HOW TO OBSERVE PLUTO FROM YOUR BACKYARD p. 46

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Astronomy®

JULY 2015

THE INSIDE STORY PLUTO

New Horizons' flyby
All you need to know p. 22

In search of death plunge asteroids p. 28

Pluto looms behind its large moon Charon while the distant Sun faintly illuminates the scene.

Get set for Asteroid Day p. 34

www.Astronomy.com

BONUS ONLINE CONTENT CODE p. 4

Vol. 43 • Issue 7

Set your sights on the Great Rift p. 48

Catch some Moon rays p. 52

Vacation with the stars p. 60

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CONTENTS

56

FEATURES

JULY 2015
VOL. 43, NO. 7

RON MILLER FOR *ASTRONOMY*

ON THE COVER

Charon (foreground) and Pluto stand ready to be revealed by the New Horizons probe when it flies past the planetary system in July.

COLUMNS

QUANTUM GRAVITY

IN EVERY ISSUE

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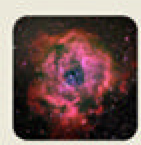

Picture of the Day
Astroimages from around the world

FROM THE **EDITOR**

BY DAVID J. EICHER

New online interactive features!

This is a big year for the Hubble Space Telescope: 2015 marks its 25th anniversary. I hope you enjoyed our April issue commemorating Hubble and all of its accomplishments.

I want you to know of an exclusive online story about Hubble with bonus graphics and interactive elements. Here is how it begins …

"There remains only the privilege of waving the astronomers farewell on their voyage to the stars — in imagination riding with the Captain on his bridge down the bay till the pilot takes us off and puts us ashore." So wrote journalist David Woodbury about the latest grand astronomical project, the building of the 200-inch Hale Telescope on Palomar Mountain, California, in 1939. The vision of astronomer George Ellery Hale, the famous 200-inch instrument was, when built, the world's largest by a factor of two and helped revolutionize knowledge of the cosmos throughout much of the 20th century.

The same could have been written half a century later, when another grand project was about to take center stage. This year we celebrate the 25th anniversary of the launch and "first light" of the Hubble Space Telescope, the greatest scientific instrument ever produced for astrophysics and cosmology. The telescope — named for Edwin Hubble, discoverer of the expanding universe — tragically flawed and heroically fixed, has fundamentally changed our understanding of the cosmos. But the story of the Hubble telescope is not one simply of challenge, trouble, and triumph. It is one that explains why we know what we know about the universe.

Since the invention of the telescope in 1609, astronomers have been plagued by the unsteadiness of Earth's atmosphere, which distorts starlight from cosmic objects. As early as 1923, rocketry pioneers conceptualized a telescope launched into space, thereby avoiding atmospheric turbulence, with its captured data sent via signals to the ground and assembled into information and pictures. In 1946, just as the Hale Telescope was nearing first light, Lyman Spitzer, an influential American astronomer, penned a paper in which he examined the advantages and challenges of a space-based telescope for the first time.

Is the Hubble telescope really that big a deal? "From the time it was conceptualized, it was clear that Hubble would revolutionize our view of the cosmos," says Avi Mandell, a planetary scientist. "The exquisite stability and clarity of Hubble's images combined with the ability to view the universe at wavelengths of light that are unavailable to observatories on Earth make Hubble by far the most powerful telescope available — even 25 years after its launch!"

You can read the entire Hubble story at www.Astronomy.com/hubble25.

We have two other online features. You can find "Why we should take the asteroid threat seriously" at www.Astronomy.com/asteroids. And "Jim Lovell and the Apollo program: Houston, we've had a problem" tells the story of Lovell's experiences with Apollo 8 and Apollo 13. Explore his adventures at www.Astronomy.com/lovell.

Yours truly,

David J. Eicher
Editor

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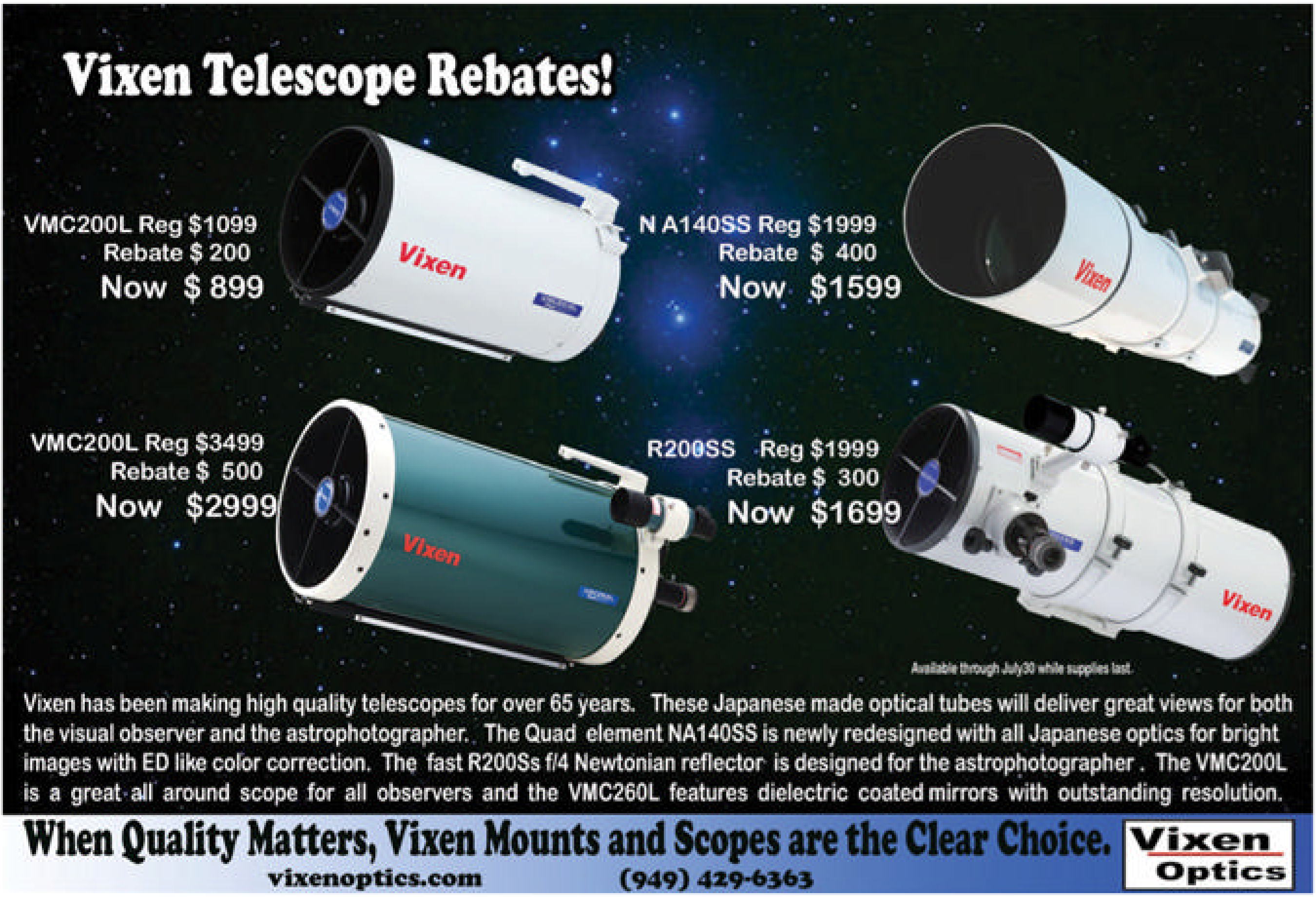

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P24529

QUANTUM GRAVITY

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH . . .

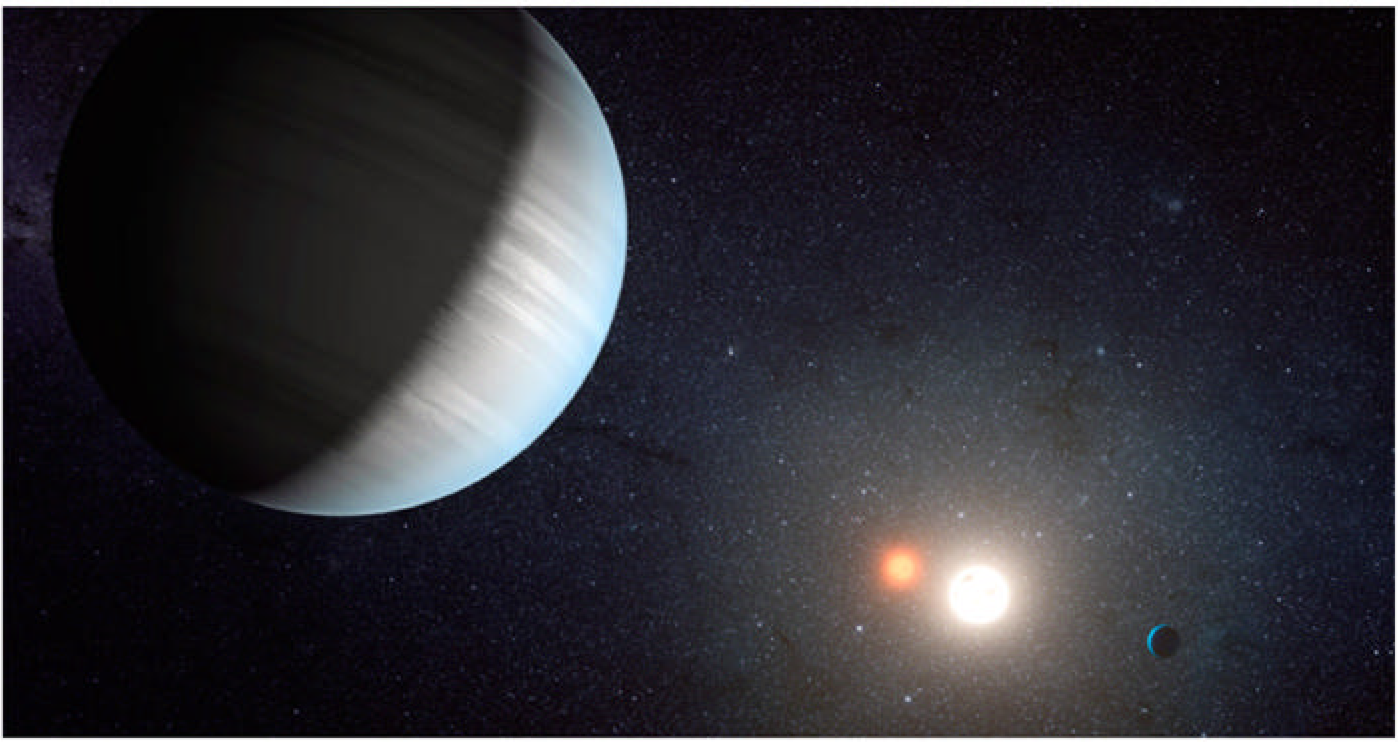
HOT BYTES>>

TRENDING TO THE TOP

CORRUGATED GALAXY
New findings show that the Milky Way may be 50 percent larger than previously estimated, with large-scale ripples.

ANCIENT IMPACT
Researchers found two 125-mile-wide (200km) scars from an asteroid that impacted Earth over 300 million years ago in Central Australia.

CERES PLUME
A bright spot in one of Ceres' craters may be a plume of outgassing material; it appears in images before the crater floor rotates into view.



NASA/JPL-CALTECH/T. PYLE (KEPLER-47); DANA BERRY (CORRUGATED GALAXY); NASA (ANCIENT IMPACT); NASA/JPL/UCLA/MPS/DLR/IDA (CERES PLUME)

This artist's sketch shows Kepler-47, the first discovered system of exoplanets with multiple planets orbiting two suns, which lies at a distance of 4,900 light-years.

SNAPSHOT

Exoplanet explosion

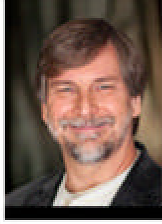
Astronomers found the first planet outside our solar system only 23 years ago. Now we have almost 2,000, and the Kepler spacecraft has uncovered several thousand more candidates.

Not long ago, the dream of discovering how common planets are in the universe was simply that — a dream. Planetary scientists believed they knew something about the formation of solar systems and thought planets might be common among other star systems, but they really didn't know.

Once astronomers found the first incontrovertible evidence for planets around another star, however, the rush of evidence accelerated. By the late 1990s, doubts about the abundance of planets in the Milky Way began to fade. In 1999, astronomers found the first system around a normal star containing multiple planets. The game was on.

By now, it has become clear that planets are common in the Milky Way Galaxy and, by inference, in the hundred billion galaxies throughout the cosmos. The Kepler space telescope, the leading tool for discovering exoplanets, has sampled only a small area of sky and to a slight "depth" throughout our galaxy, and yet we already see that planets are ubiquitous.

This tells us that Earth is probably not special — that there are probably numerous Earth analogs throughout the Milky Way and the universe. Yet that fact is amazing and makes our lives even more connected to the cosmos at large.
— David J. Eicher

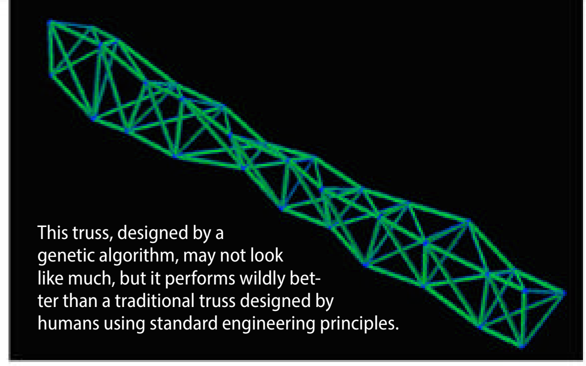


FOR**YOUR**CONSIDERATION

BY JEFF HESTER

It's genetic

Returning engineering to its roots.



This truss, designed by a genetic algorithm, may not look like much, but it performs wildly better than a traditional truss designed by humans using standard engineering principles.

ANDY KEANE

I recall the first time that I saw the famous movie of the windy November morning in 1940 when the Tacoma Narrows Bridge, connecting Tacoma and the Kitsap Peninsula across Puget Sound in Washington, tore itself to pieces. There she was, "Galloping Gertie" as the bridge was known, wildly bucking and twisting in a 40 mph (60 km/h) wind. Then, suddenly, in a matter of only a few seconds, the third-longest suspension bridge ever built at the time was no more! To this day, the Tacoma Narrows Bridge remains a textbook example of engineering gone wrong. Structures are subject to vibrations, and if you aren't careful, those vibrations can spell big trouble.

Enter Professor Andy Keane. The year is 1994, and Keane and his colleagues at Southampton University in the UK are working to design a much smaller bridge — a truss — that is as vibration-free as possible. They aren't worried about the extreme oscillations that destroyed Gertie, but they do care about the slight vibrations that would cripple a delicate instrument like an astronomical satellite. They start with a traditional design, but that's where tradition ends. Instead of using their knowledge and insight to improve the design in clever ways, they metaphorically throw intelligence out the window. They hand the job over to a computer and then kick back and wait to see what happens.

The computer itself is kept intentionally dumb. It doesn't know anything about engineering design principles. It only can do two things. First, it can make new virtual trusses by combining and randomly changing the properties of existing trusses. Second, it can compare trusses and tell better from worse. Armed with no other tricks up its sleeve, the computer marches along, blindly turning the crank:

Step 1: Make a new generation of trusses by shuffling and making random changes in the previous generation.

Step 2: Evaluate the new trusses, and toss the ones that don't work so well.

Step 3: Repeat. Again, and again, and again …

UNIVERSITY OF WASHINGTON

The Tacoma Narrows Bridge collapse in 1940 is a textbook case of failed engineering.

Ten generations and over 1,000 virtual trusses later, the computer's best effort is lopsided and twisted and irregular. It looks more grown than designed. Nobody understands it or has the faintest clue how it works. But it does work. It works very well. The vibrations have been improved by more than 20,000 percent!

Keane was not the first to take this approach to design, and he certainly wasn't the last. Two decades later, such unguided, blind algorithms are revolutionizing our approach to the shapes of airplane wings and turbine blades, new molecules for industrial and pharmaceutical uses, pattern recognition, communications networks, investment strategies, cancer treatments, and hundreds of other applications.

At their core, all of these applications have two things in common: (1) the better an item performs, the more likely its properties will be retained; and (2) when surviving properties are passed on from one generation to the next, variations occur. As long as these two conditions are met, properties will evolve from generation to generation as items become better and better suited to their task.

By the way, life satisfies these two conditions. When evolutionary biologists talk about the first condition, they call it "selection." When they talk about the second condition, they call it "heredity with variation." And like any other system that satisfies these conditions, life evolves. Logically, life can't help but evolve! In one sense, engineers who employ genetic algorithms to evolve technologies are doing something new. But in a deeper sense, they are returning engineering to its roots, tapping the power of the mindless algorithm that has been shaping life for almost 4 billion years.

The public discussion of biological evolution is undeniably muddled. In part that is because people tend to approach it from the wrong direction. Darwin's voyage on the *Beagle* deserves to be the stuff of legend, but if you want to understand evolution, forget about finch beaks or fossils. Instead, talk to a working engineer who is using genetic algorithms to evolve a truss.

Once you've wrapped your head around how and why a truss gets so good so quickly, you have the understanding you need to approach evolution as scientists do. You can use that understanding of evolution to make predictions about the world and then see whether those predictions hold true. When you do that, you discover that the predictions of evolution are in remarkable accord with all that we see. From the fossil record to the common chemistry of life, to the shared structure of different species — and now to pharmaceuticals, jet engines, and bridges — we live in a world crafted by evolution's unguided hand.

Jeff Hester is a keynote speaker, coach, and astrophysicist. Follow his thoughts at **jeff-hester.com.**

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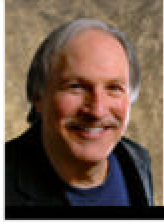


STRANGE**UNIVERSE**

BY BOB BERMAN

Send astronauts to Zappafrank

Exploring how we name the universe.

Celebrities know that names have power. That's why Robert Zimmerman and Cherilyn Sarkisian decided to call themselves Bob Dylan and Cher. Yet little poetry or stateliness was employed when it came to naming the universe's contents. Indeed, astronomy possesses the most inconsistent nomenclature in all of science. Here's a primer for newbies — and a refresher for the rest of us.

The brightest stars enjoy proper names, though just a few dozen remain in use today. Some have punch, like Sirius and Arcturus. Such names also serve to recall ancient mythologies. Medium-bright stars are referenced by a different system created in the 17th century, when 1,564 stars got mostly Greek letter designations, like Gamma (γ) Arietis.

The majority of stars — over a million have been cataloged — remain unnamed or at best possess long strings of license plate-like letters and numbers. The star orbiting the black hole Cygnus X-1 is HDE 226868 but also called BD+34 3815.

Move to the planets (beyond ours), and we get the names of Roman gods, although Uranus came from the Greeks. As for planetary features, major ones sport kindergarten labels like Neptune's "Great Dark Spot" and Jupiter's "Great Red Spot." But smaller features like valleys possess disparate mind-numbing designations. Who's responsible for that?

The International Astronomical Union (IAU), that's who. The IAU is alone empowered to name the contents of the cosmic supermarket. Newly found mountain chains, craters, and the like follow the IAU's strict guidelines. Its rules fill pages and pages. Consider a few of Saturn's moons.

Different feature types have different naming requirements on Titan. For example, craters are named for gods of wisdom, while mountain peaks come from J. R. R. Tolkien's fictional Middle-earth mountain ranges. All features on Iapetus must bear the names of people and places from Dorothy Sayers' translation of *La Chanson de Roland*. Those on Rhea must be people and places from creation myths, while ones on Mimas must be people and places from Sir Thomas Malory's *Le Morte D'Arthur* legends, specifically the 1962 Keith Baines translation. And on it goes. No movie stars or cartoon characters.

Moons named before the IAU arrived on the scene display an enjoyable inconsistency. The martian satellites Phobos and Deimos (the Greek personifications of fear and dread, respectively) take the "most depressing" prize. Uranus' moons are mostly characters from Shakespearean plays, which is why there are actual celestial bodies named Puck and Juliet.

As for *our* Moon, many of the dark blotches or "seas" are bizarrely named for emotions (Sea of Tranquillity, Sea of Cleverness) or weather phenomena (Ocean of Storms, Sea of Clouds). Features on the lunar backside have Russian names, the embarrassing result of that country's Luna 3 arriving there first, in 1959. As for Full Moons, TV newscasters sometimes urge viewers to watch the upcoming "Wolf Moon" or "Strawberry Moon." But only the Harvest and Hunter's Moons are official names. The 12 or 13 yearly Full Moons labeled by various Native American tribes are contradictory and mostly ignored, like this month's Buck Moon.

Asteroids are another story. They started out derived from Roman and Greek mythology but then changed over to a free-for-all, with names proposed by the discoverer and approved by the IAU. Only 5 percent of numbered asteroids have names, a motley assortment of people and even their relatives. You'll find asteroid 3252 Johnny (for Johnny Carson) and 3834 Zappafrank. Mainstream scientists were favored, but not controversial or unpopular ones. Classical asteroids are there too, like Eros. Craters on Eros are labeled for "mythological and legendary names of an erotic nature." How did *that* category make it through the stodgy IAU council? Must've been a late-night session.

Meteor showers are named for constellations, meteorites for whatever place on Earth they smashed into. Comets are the only objects named for their discoverers, who then become the sole authority on the pronunciation.

The floating Rorschach tests called nebulae do not generally receive new names. But we retain the labels bestowed in olden times. Long ago, someone thought one gas cloud looked like a dumbbell from the weight room at the local gym, a place not generally frequented by astronomers. The "Dumbbell Nebula" label stuck, as did the results of early astronomers saying, hey, look at that: An Eskimo! And there's a Crab!

As for the universe's largest structures — galaxies — some 200 billion are visible and millions cataloged, but only a couple dozen are named. These star cities are honored by things like a hat (the Sombrero Galaxy), an injury (the Blackeye Galaxy), and a tobacco product (the Cigar Galaxy). But the vast majority merely have number designations like NGC 6217.

Obviously there's a sizeable gap between the cosmos' inspirational contents and its odd or mundane labels. Few beginners would be inspired upon hearing of a "B ring" or galaxy "NGC 205" in the "Local Group." Nonetheless, this hodgepodge system is not going to change, and even has a strange appeal. It's shared by no other science. As astronomers, we affectionately know that it's ours alone.

CRATERS ON EROS ARE LABELED FOR "MYTHOLOGICAL AND LEGENDARY NAMES OF AN EROTIC NATURE."

Contact me about my strange universe by visiting **http://skymanbob.com.**

FROM OUR INBOX

Are there aliens out there?

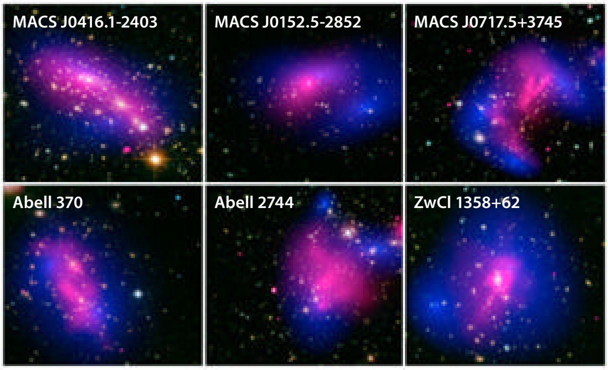
My first reaction to "Let's cut the UFO crap" (March issue, p. 9) was disappointment in the editor of a great magazine. Next, I felt that such bullying arrogance about a view you hold is an insult not only to those having the opposite view, but also to everyone. Who would disagree with one who calls those with other views naïve? Scientists, pilots, and presidents have professed seeing UFOs. Do we demean all of them?

— Jim Hoover, Huntington Beach, California

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman.**

ASTRONEWS

PRIMITIVE STARS. Two stars in the Sculptor Dwarf Galaxy contain extremely few elements heavier than helium, indicating that they formed from gas enriched by only one supernova, probably one of the first stars formed in Sculptor.



CRASH SITES. By studying galaxy cluster collisions, like the six shown here, astronomers have mapped the movement of dark matter (shown in blue) and found that it interacts with itself even less than previously thought. NASA/ESA/D. HARVEY (EPFL/UNIV. OF EDINBURGH)/R. MASSEY (DURHAM UNIV.)/T. KITCHING (UCL)/A. TAYLOR & E. TITTLEY (UNIV. OF EDINBURGH)

DARK MATTER EVADES . . . ITSELF?

Ever since the "missing mass problem" came to the forefront of galaxy studies in the 1930s, scientists have been looking to answer the question of dark matter. They can't see it in any part of the electromagnetic spectrum, but they can infer its existence based on the gravitational effects it has on the surrounding universe. Because of its mysterious properties, astronomers spend most of their time trying to determine what dark matter is by eliminating what it can't be. In a recent study of 72 galaxy cluster collisions, published in the March 27 *Science*, a team led by David Harvey of the École Polytechnique Fédérale de Lausanne in Switzerland has narrowed down the options in a surprising find.

"We know how gas and stars react to these cosmic crashes and where they emerge from the wreckage," Harvey says. "Comparing how dark matter behaves can help us to narrow down what it actually is." What they found when studying these collisions with the Hubble Space Telescope and Chandra X-ray Observatory is that the dark matter didn't slow down with the impacts, meaning the particles interact with each other even less than previously thought. Such a characteristic rules out dark matter particle candidates that have a strong frictional force.

"There are still several viable candidates for dark matter, so the game is not over," says Harvey, "but we are getting nearer to an answer." — **Karri Ferron**

BRIEFCASE

DO MOST STARS HAVE HABITABLE PLANETS?

Jupiter's three inner moons have a distinct one, two, four orbital resonance. The planets have a similar resonance around the Sun, as noted by the Titius-Bode law. This concept was used to correctly predict the orbit of Uranus (though it failed to pin down Neptune). Astronomers applied this simple framework to the Kepler spacecraft's exoplanet catalog and, by filling in the blanks with the Titius-Bode law, showed most known solar systems could have planets orbiting in their habitable zones. Their work appeared in the April 21 issue of the journal *Monthly Notices of the Royal Astronomical Society.*

•

YOUNG EARTH BLANKETED BY IRON RAIN

Why does Earth have so much iron spattered across its mantle while the Moon has so little? Astronomers used the Sandia National Labs Z machine to unravel this long-standing mystery. Their research appeared in the April *Nature Geoscience*. Instead of arriving in large blobs from asteroids, they found that iron could be vaporized on impact and spread out, blanketing the planet and raining down in droplets.

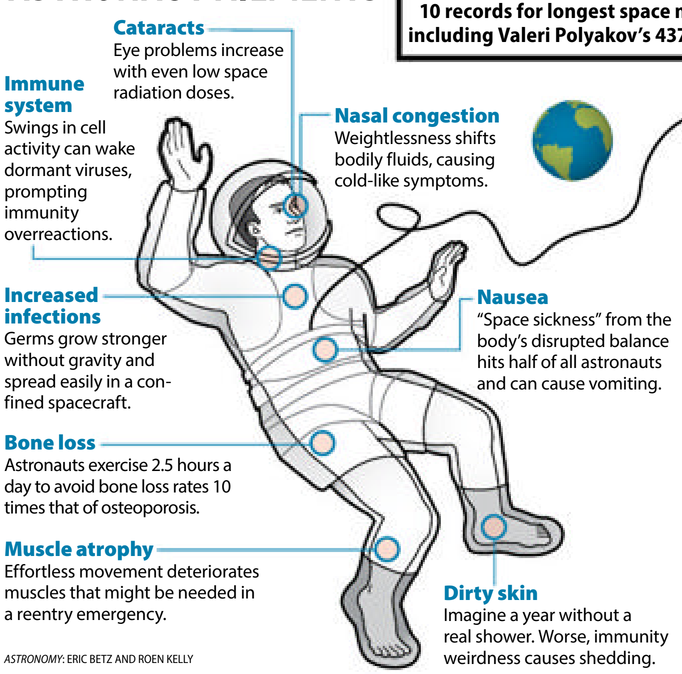
•

ODD GALAXY A SHORTCUT TO COSMIC ORIGINS

Heavy elements are extremely scarce in a (relatively) nearby dwarf galaxy with an unfortunate name, I Zwicky 18, according to a paper published March 10 in *The Astrophysical Journal Letters*. It has abundant hydrogen and helium, but few metals. That makes it similar to our universe's first galaxies and a good proxy for studying those very faint island universes. Already astronomers think supermassive stars in I Zw 18 might be the key to understanding its strange composition, but they've yet to see such monsters directly. — **Eric Betz**

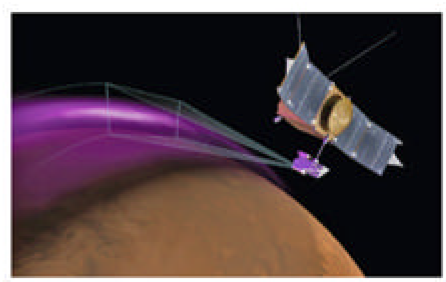
ASTRONAUT AILMENTS

Russian cosmonauts hold nine of the 10 records for longest space missions, including Valeri Polyakov's 437-day trip. FAST FACT



ASTRONOMY: ERIC BETZ AND ROEN KELLY

TWIN PARADOX. Scott Kelly's one-year space station mission, while NASA studies his brother, Mark, on Earth, benefits from more than 50 years of spaceflight. And while engineers have mastered many short-term risks, a more fundamental question remains: Can humans survive years in space? Galactic cosmic rays are now known to cause cancer by breaking DNA strands in complex ways, making it hard to repair cells. But that's far from the only problem Kelly faces.



UNIVERSITY OF COLORADO

UNEXPLAINED LIGHTS. NASA's MAVEN spacecraft watched "Christmas lights" for five days in 2014.

MAVEN sees mystery Mars clouds

It didn't take long. NASA's MAVEN spacecraft reached the Red Planet in September and spotted dust clouds and aurorae at altitudes that defy current Mars knowledge.

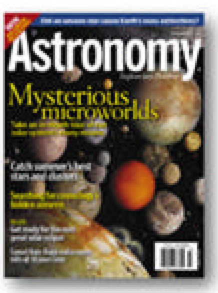
Scientists say the thin dust is seen at orbital altitudes between 93 and 190 miles (150 and 300 kilometers) and has been there since MAVEN arrived. The clouds may have formed in the atmosphere, been swept up from the surface, or even gotten stripped from Mars' moons.

NASA also caught five days of "Christmas lights" in the run up to December 25. The bright ultraviolet glow of aurorae spanned the planet's entire northern hemisphere and followed a surge in electrons streaming off the Sun. — **E. B.**

RINGED CENTAUR. Chiron was the first identified centaur, with qualities of both asteroids and comets. MIT researchers recently observed it to have encircling debris, which might be rings or symmetric jets from its surface.

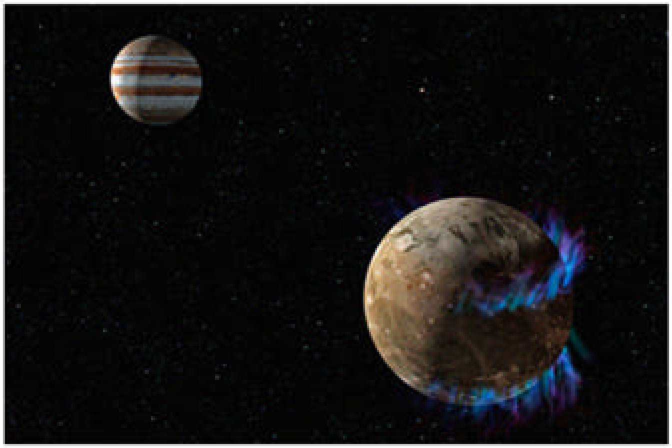
25 years ago in *Astronomy*

Planetary scientist Alan Stern voiced support for a Pluto flyby mission in *Astronomy*'s July 1990 "Viewpoints" section. He argued: "One need only remember how wrong early ideas about Mars and Venus were, before the Mariner expeditions, or how enigmatic Io and Titan were before Voyager. Everywhere we have been we have learned that Earth-based studies, no matter how sophisticated, necessarily underestimate the richness and diversity of complex physical properties awaiting us." Stern takes his seat in the captain's chair as New Horizons zooms past Pluto this month.



10 years ago in *Astronomy*

Astronomy's July 2005 cover story delved into the many "microworlds," or moons, that inhabit our solar system. British science writer Jacqueline Garget walked readers through the latest finds from the Huygens probe's first look beneath Titan's veil and chances of life on Europa. — **E. B.**



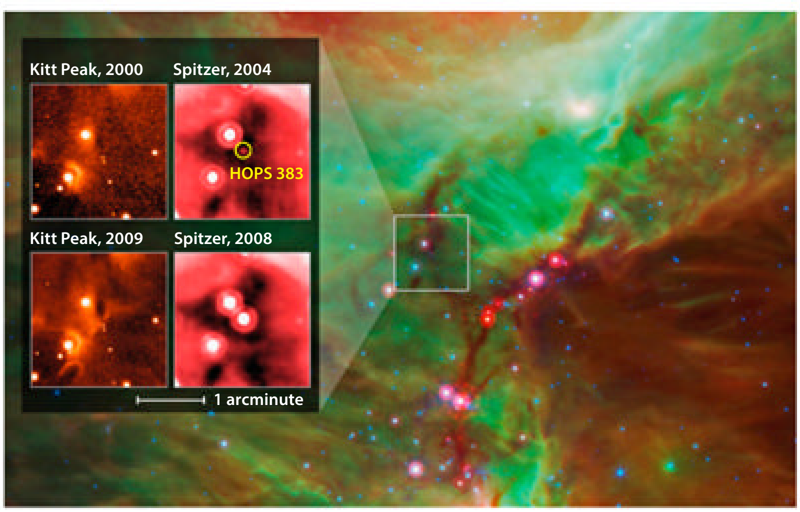
DUELING AURORAE. Astronomers used the interactions between Jupiter's and Ganymede's aurorae to discover an ocean hidden 95 miles (150km) beneath the moon's surface. NASA/ESA

Inner ocean hides in outer solar system

In research published online March 12 in the *Journal of Geophysical Research: Space Physics*, astronomers delivered the first observational evidence that Jupiter's moon Ganymede has a vast underground ocean. Ganymede, the largest moon in the solar system, is also the only moon to host its own magnetic field, causing aurorae that were the key to discovering the secret sea. These aurorae have been spotted before on Ganymede, and an ocean seemed likely based on models, but there wasn't enough data for astronomers to do more than theorize.

New ultraviolet time-series observations from Hubble delivered the long-awaited proof. Ganymede's magnetic field is complicated because it lies within and is affected by Jupiter's stronger magnetic field, causing the aurorae to "rock" by 2°. However, a solid Ganymede should show a stronger rocking effect of 6°. The rocking could be damped if a counter field were induced by Jupiter's magnetic field; the magnitude of the damping would require a 60-mile-deep (100 kilometers) underground saltwater ocean to carry the opposing force. — **Korey Haynes**

Protostar hits growth spurt



E. SAFRON, ET AL.; BACKGROUND: NASA/JPL/T. MEGEATH (UNIV. OF TOLEDO)

TEMPER TANTRUM. Within just a few years, HOPS 383 grows dramatically hotter in Spitzer infrared images, changing from nearly invisible to super bright.

A 10-year-old catalog of Spitzer data pointed the way toward a surprising stellar eruption. The young protostar HOPS 383 is still in the first stage of collapsing, surrounded by a thick disk of dust and gas, and as yet is unable to fuse hydrogen like an adult star. After noticing it behaving strangely in Spitzer images, astronomers collected data from multiple other telescopes. Between 2006 and 2012, HOPS 383 brightened by a factor of 35 and remained bright. The team attributes this flare-up to instabilities in the disk, which cause large amounts of material to fall onto the protostar. This in turn causes the star both to brighten and heat its disk. They published their findings in *The Astrophysical Journal* February 10. — **K. H.**

QUICK TAKES

ECLIPSE SCIENCE
Aside from the stunning visual treat, astronomers used the March 20 total solar eclipse to study the Sun's corona and observe the eclipse's effect on Earth weather.

TEAM ROCKET
The rocket booster that is intended for NASA's Space Launch System and Orion was successfully test fired for two minutes, producing 3.6 million pounds of thrust.

MARTIAN MARATHON
NASA's Opportunity rover completed its first marathon on Mars, traveling 26.2 miles (42.2km) since its arrival over 11 years ago.

ICY DUST
Rosetta's OSIRIS team found bluish reflections around the "neck" region of Comet 67P/Churyumov-Gerasimenko, possibly indicating water ice is mixed with the surface dust.

NEW STANDARD
New observations from GALEX show that certain type Ia supernovae, often called "standard candles" for their predictable light and use as distance indicators, are more standard than others.

DUST PILE
NASA's SOFIA, an infrared observatory mounted on a modified Boeing 747, discovered 7,000 Earths' worth of dust around the supernova remnant Sagittarius A East.

NOISY STARS
Laboratory scientists have proven that rapidly flowing plasma, like that seen around stellar surfaces, can produce pressure pulses in the form of sound waves — though in space, you'll never hear them.

SPACE RAIN
The Chandra X-ray Observatory revealed hot gas blown out from black holes falling back onto the black hole. This process is called cosmic precipitation and can trigger hot jets and shut off star formation.

MANY SUNS
Astronomers found a planet in the quadruple star system 30 Arietis. This is the second planet found to orbit four stars, indicating such systems may be common. — **K. H.**

OBSERVING**BASICS**

BY GLENN CHAPLE

Stellar time machines

Add the stars of summer to your time travel escapades.

ASTRONOMY: KELLIE JAEGER

In my January column, "Time travel," I spelled out the distances to the brightest stars of winter, not just in light-years but in worldly events that occurred when their light began the journey earthward. With summer in full swing (at least in the Northern Hemisphere), let's take a trip back in time with some 1st-magnitude stars currently visible in northern skies.

Altair (16.7 light-years): If you're a member of the college graduating class of 2015, Altair has been your guiding star throughout your learning years. The light you see left its surface in late 1998 when you were about to enter kindergarten and touched down on Earth as you received your diploma! Space enthusiasts recognize the latter part of 1998 as the time when construction of the International Space Station began.

Vega (25 light-years): A few months ago, *Astronomy* devoted an entire issue to the 25th anniversary of the Hubble Space Telescope. It launched aboard the space shuttle April 24, 1990, around the time Vega launched the light currently raining down on our planet. Since then, Hubble has traveled more than 3 billion miles (5 billion kilometers) in Earth orbit. That's impressive, until you consider that Vega's light covered that distance every five hours. Warp drive is still a long way off!

Arcturus (37 light-years): The light we're receiving from Arcturus left during the summer of 1978. The Pioneer 11 spacecraft had passed Jupiter 3½ years earlier and was one year away from its Saturn encounter. Back in 1933, Arcturus made headlines when its light was used to turn on the beacon that opened the Chicago World's Fair. The choice of star was hardly random; astronomers at the time thought those photons had left Arcturus at about the time of the previous Chicago fair in 1893.

Spica (250 light-years): Gaze at Spica, and your eyes are taking in light that left during the mid-1760s when friction between colonial America and England was on the rise. In France, comet hunter Charles Messier was busy compiling a catalog of nebulous objects. Wolfgang Amadeus Mozart, still a child, had already composed his first symphony.

Antares (550 light-years): As is the case with winter's remote stellar luminaries Betelgeuse and Rigel, the distance to Antares is iffy. If we accept the parallax data gathered by the Hipparcos satellite, Antarean light left around 1465 during the European Renaissance. Christopher Columbus and Leonardo da Vinci were teenagers embarking on paths that would lead to their history-making accomplishments as world explorer and artist/inventor, respectively. In the Americas, both the Aztec and Inca empires were flourishing.

Deneb (1,425 light-years): When Deneb's light left during the latter part of the sixth century, the world was a battleground as tribes and kingdoms waged war with swords and bows and arrows. Civilization has come a long way during the intervening centuries. Today, we use tanks and guided missiles.

After reading my January column, several readers emailed to ask if I was familiar with the YouTube clips "Dr. Clay's Time Machine, parts 1 and 2," based on a lecture given by Dr. Clay Sherrod in 2011. Had I stolen his idea? Nope! The concept for the article came from a practice I'd been using at public star parties for years to express star distances in a more meaningful way. I picked it up after attending a lecture at an astronomy convention back in the mid-1970s. The speaker, the late astrophotographer Ben Mayer, related how his interest in astronomy was ignited upon learning that the majority of stars in the Big Dipper are 80 light-years away. His grandmother had recently passed away at that age, and when gazing at these stars, he realized that their light had been traveling across space during her entire lifetime.

Unfamiliar with Sherrod's clips, I sat down at the computer to view them for myself. To be sure, he described star distances much the way I had. But he took my stellar time machine article to a whole new level by adding the solar system, Milky Way Galaxy, neighboring and distant galaxies, and the outermost reaches of the universe. On the next cloudy night, hop aboard Sherrod's Delorean (a nod to Professor Emmett Brown's time machine in the 1985 film *Back to the Future*) and take a "blast to the cosmic past." It's an hour well spent!

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: Here comes the Sun! Clear skies!

FROM OUR INBOX

Cool things

Congratulations on your 500th edition of *Astronomy* (March 2015). The "500 coolest things about space" was a great idea.

I give monthly slide presentations at the local observatory open houses for our astronomy club's outreach programs. I've been reading your magazine and taking notes for over 20 years. The notes are saved and used to supplement my talks. These little facts are what keep my programs interesting. Now, thanks to you, I have more "cool things" to present to my audience.

— **Tom Rusek,** Aberdeen, Maryland

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple.**

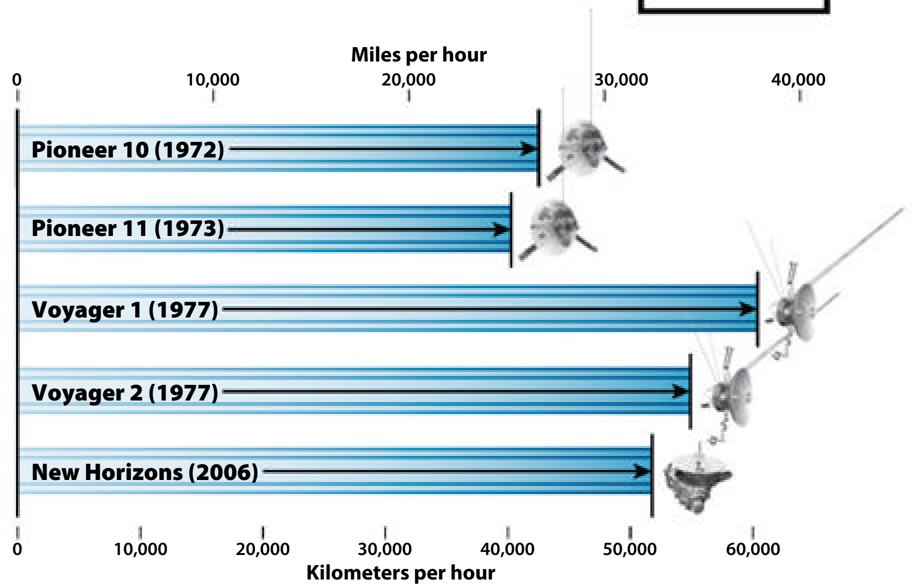
ASTRO**NEWS**

E.T. HUNTING. NIROSETI, a new campaign to look for alien intelligence signals in the infrared, saw first light at Lick Observatory on March 15.

HOW FAST ARE SPACECRAFT TRAVELING, RELATIVE TO THE SUN?

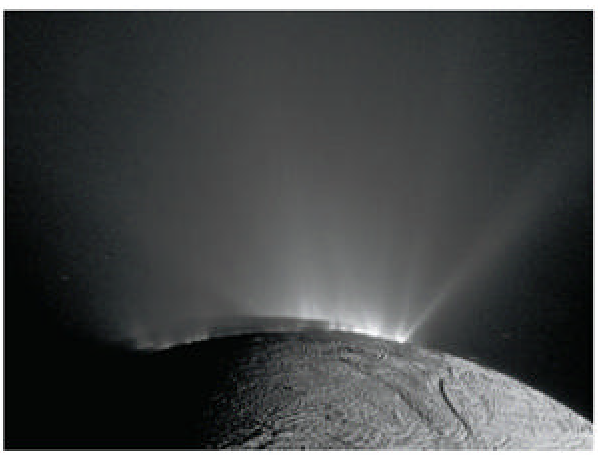
Earth orbits the Sun at 66,469 mph (107,208 km/h).

FAST FACT



NEED FOR SPEED. The five NASA spacecraft on escape trajectories all flee the solar system at different speeds, thanks largely to the different gravity assists each mission took on its way toward interstellar space. Note that while Earth goes only round and round, it easily outstrips even Voyager 1's blistering pace. *ASTRONOMY:* KOREY HAYNES AND ROEN KELLY

Hydrothermal vents brew in Enceladus' ocean



NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE

GEYSER SOURCE. NASA's Cassini spacecraft watched plumes of water and ice stream off Enceladus' south pole over the past decade. Now researchers have used the spacecraft to trace the origins to specific geyser groups.

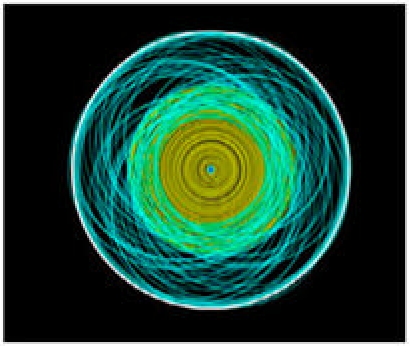
Last year, tiny variations in the tug on NASA's Cassini spacecraft revealed an ocean beneath Enceladus' icy shell. Scientists deduced that the the saturnian moon's ocean is around 6 miles (10 kilometers) deep and covered by ice that reaches anywhere from 19 to 25 miles (30 to 40 km) thick.

Now astronomers know that those oceans of liquid water are also home to hydrothermal vents. In March, scientists published a new analysis, focusing on tiny particles of silica that Enceladus feeds into Saturn's icy E ring. Laboratory experiments showed that these particles were likely created deep down in an ocean under temperatures that could reach 194° F (90° C). These conditions would be similar to hydrothermal vents on Earth called black smokers, where entire ecosystems thrive on chemical energy deep in the ocean.

In May's *Astronomical Journal*, astronomers also announced they have traced the source of long icy tendrils that stretch out into that E ring to specific groups of geysers erupting off the moon's surface. These tendrils can reach tens of thousands of miles from Enceladus. "We've been able to show that each unique tendril structure can be reproduced by particular sets of geysers on the moon's surface," says Cassini imaging team associate Colin Mitchell.

Cassini team members say that Enceladus' potential to harbor life makes it a prime target for the mission's final years, and scientists plan to make extensive observations of the moon's geyser basins, plumes, and tendrils. — **E. B.**

ASTRO**NEWS** **STATION SWITCH.** On March 27, three new space travelers from the United States and Russia joined the International Space Station crew. Astronaut Scott Kelly and cosmonaut Mikhail Korneinko will remain on board the space station for a full year.



SMASH BROS. In a new theory, Jupiter (orbit shown in white) migrated inward, pushing a swarm of space rocks on eccentric orbits (turquoise) into the path of close-in planets (yellow), where they collided and were destroyed. K. BATYGIN/CALTECH

Jupiter came in like a wrecking ball

For decades, astronomers have had trouble modeling exactly how our solar system could have formed. It doesn't resemble the exoplanet systems observed by Kepler and other surveys, and most simulations have difficulty explaining the rocky planets' masses and positions. A model called the Grand Tack scenario posits that Jupiter and Saturn could have formed at some orbital distance and then spiraled in toward the Sun and back out again due to changes in the gaseous disk of the early solar system. They would have shepherded a cloud of rocky debris in with them, abandoning it roughly around Earth's orbital area when they moved out again. This explains some peculiarities of the solar system, but not all.

Astronomers from the California Institute of Technology offer a new theory, published in the April 17 issue of the *Proceedings of the National Academy of Sciences*, that expands on this model. They suggest that the early solar system also contained a herd of super-Earths at close orbital distances, as commonly seen in exoplanet systems. Jupiter and Saturn's abandoned swarm of debris, left on highly eccentric orbits, would only take about 20,000 years to systematically smash into and destroy the super-Earths, sending the remains plummeting into the Sun. The leftover material at safer distances would eventually form the rocky planets that remain today, so that the new theory neatly explains both our modern solar system's appearance and its lack of resemblance to the exoplanet systems we observe elsewhere in the galaxy. **— K. H.**

10:32:44
hours minutes seconds

Length of Saturn's day, according to a new estimate published in the journal *Nature.*

SPACE SCIENCE UPDATE

MESSENGER'S END BRINGS IT UP CLOSE WITH AN ACTIVE PLANET

The first spacecraft to orbit the innermost planet ran out of fuel and crashed on April 30, following a series of planned maneuvers that brought it closer to Mercury's surface than airplanes fly on Earth. MESSENGER's final daredevil skims showed scientists fresh evidence that this Sun-scorched world is not entirely dead.

Among the close-ups were scenes of ice deposits in crater shadows, linear fault scarps formed as the planet shrinks, and an abundance of strange depressions that pockmark the surface across anywhere from a few dozen feet to several miles.

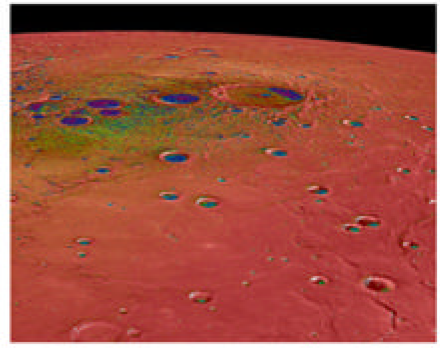
"These features, given the name 'hollows,' were a major surprise because while we had been thinking of Mercury as a relic — a planet that wasn't really changing anymore — hollows appear to be younger than the planet's freshest impact craters. This finding suggests that Mercury is a planet whose surface is still evolving," says MESSENGER scientist David Blewett of Johns Hopkins University. The team suspects the hollows form as something in the rock sublimates, which typically happens when a substance changes from an ice to a gas without melting into a liquid.

When MESSENGER arrived at our solar system's inner frontier in 2011, much of Mercury was still a mystery because spacecraft had imaged less than half its surface. Scientists hoped to find out how the planet formed and explain why it has a magnetic field when Mars and Venus do not.

Thanks to more than four years and 4,000 orbits, scientists have now mapped Mercury's entire surface and gathered more than a quarter-million images. X-ray and gamma-ray spectrometers on board allowed for the first global geochemical maps of surface composition, deciphering the planet's history of impacts and volcanism. And MESSENGER's instruments watched Mercury's diminutive magnetic field grow and shrink in response to the active Sun.

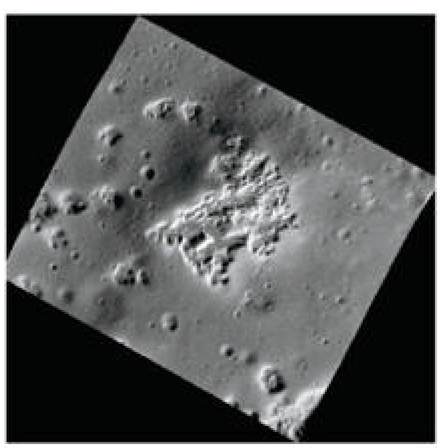
One big question still remains: How did Mercury get its large iron core?

Mission managers initially expected their spacecraft to make its final plunge sooner. But in March, NASA extended that demise by a month, pushing MESSENGER's D-day out to the end of April. Astronomers hope that the last weeks of high-resolution images will uncover new secrets as to how the innermost planet formed and evolved. **— E. B.**

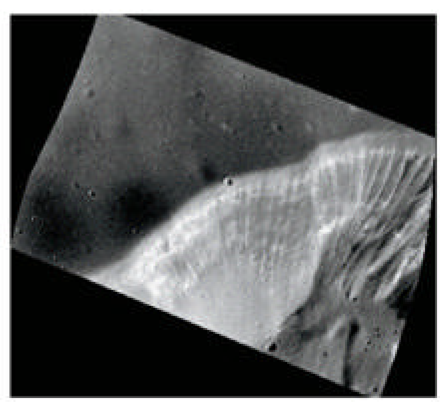


NASA/JHUAPL/CIW

FIRE AND ICE. This color-coded image (red is hot and blue is cold) from NASA's MESSENGER spacecraft shows the incredible temperature contrast between sunlight and shadow on Mercury, which can reach hundreds of degrees.



HOLLOWED GROUND. Close-up views of mysterious "hollows" show a lack of craters, implying the features are far younger than the rest of the surface.



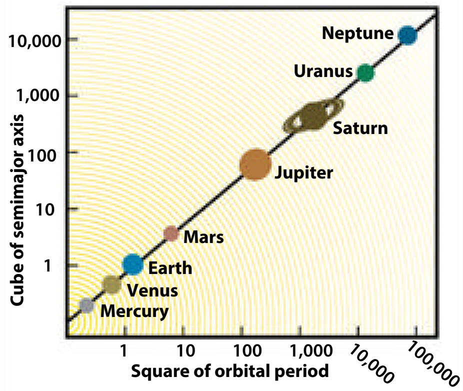
NASA/JHUAPL/CIW

PARTING SHOTS. Long flute-like gullies line the steep walls of a volcanic vent on Mercury in this high-resolution image from NASA's MESSENGER spacecraft. Without the final low-altitude mission phase, close-ups like these would not have been possible.

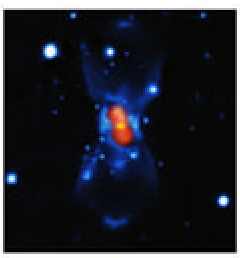
FAST FACT

One application of Kepler's third law is that the closer a planet is to the Sun, the faster it moves in its orbit.

KEPLER'S THIRD LAW



MATHEMATICAL MOVEMENT. German mathematician Johannes Kepler's third law of planetary motion is a relationship between the orbiting object's period of revolution and its semimajor axis. Textbooks usually state the relationship as $P^2=ka^3$, where P is the object's period, a is its semimajor axis, and k is a constant. *ASTRONOMY*: MICHAEL E. BAKICH AND ROEN KELLY



RARE REMNANT. New submillimeter data (shown in yellow and red) from the area around Nova Vul 1670 reveal that the historic outburst was in fact not a new star but the result of a rare merger of two stars. ESO/T. KAMIŃSKI

Mystery around historic nova finally solved

In 1670, astronomers noted a "new star" within the current boundaries of the constellation Vulpecula. It was easily visible to the naked eye, varying in brightness over the course of two years before vanishing. Although modern catalogs label it Nova Vul 1670, scientists admitted that its properties didn't fit a typical nova, and they were unable to find a remnant in the area of the outburst until 1982. What could 17th-century astronomers have seen?

According to research published in the April 16 issue of *Nature*, scientists now conclude that the best explanation is a rare merger of two stars. A group led by Tomasz Kaminski, who was at the Max Planck Institute for Radio Astronomy in Germany at the time of the observations, used the APEX telescope in Chile to reveal hidden emission in the region with the instrument's increased sensitivity. "We have found that the surroundings of the remnant are bathed in a cool gas rich in molecules, with a very unusual chemical composition," Kaminski says. The new data best match models of rare events called red transients, where a star explodes due to a merger with another sun, leaving behind only a faint stellar remnant cocooned within cool, chemically rich molecular gas. — **K. F.**

SECRETSKY

BY STEPHEN JAMES O'MEARA

Two odd couples

A pair of star clusters will intrigue careful observers.

The Double Cluster (NGC 869 and NGC 884) in the constellation Perseus is the night sky's best example of an open star cluster pairing. It's also one of the most striking sights through backyard telescopes. These two roughly 5th-magnitude clusters — each a dazzling citadel of crystal starlight — span two Moon diameters in apparent extent and are separated by a mere 25'.

Under a dark sky, they're even a wonder to unaided eyes, appearing as fuzzy knots midway along the gentle sleeve of the Milky Way that stretches between magnitude 2.7 Ruchbah (Delta [δ] Cassiopeiae) and magnitude 2.9 Gamma (γ) Persei. While the Double Cluster stands alone in its brightness, symmetry, and grandeur, the night sky holds other examples of open star cluster pairings, though most are visual oddities at best.

Stately differences

I'll start with the popular open star cluster M35 in Gemini and its "accidental companion," NGC 2158. To the unaided eye, M35 is a good example of what a single component of the Double Cluster would look like shining on its own. This 5th-magnitude cluster spans nearly a Full Moon's diameter of sky and appears as a mottled splotch of diffuse light just 2.3° northwest of Propus (Eta [η] Geminorum). Through binoculars, the view is a splendid sight because M35 ranks as one of the richest open clusters, having some 200 stars crammed into a field of view 30' across.

But if you avert your gaze only 26' southwest, you may spy M35's dim (magnitude 8.6) and diminutive (5' across) visual companion, NGC 2158. I say visual because M35 and NGC 2158 are only line-of-sight companions, with NGC 2158 being farther out by a factor of six.

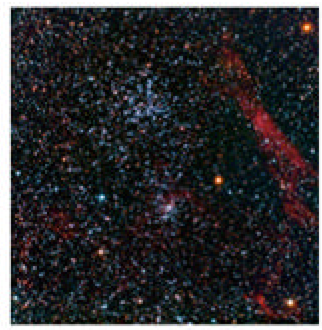
Open clusters M35 (large, center) and NGC 2158 (lower right) form an easily seen pair in the constellation Gemini the Twins. GERALD RHEMANN

Also, unlike the Double Cluster, whose components shared a common birth from the same cloud of dust and gas, M35 and NGC 2158 lie at opposite ends of the evolutionary scale, with the former being about 130 million years old and the latter being about a billion! Consider this when you take in little NGC 2158's pale milky glow; the cluster's stars may be a challenge to resolve through small telescopes because its brightest stars shine around 13th magnitude.

A near twin … but different!

M38 is one of three great open star clusters in Auriga. This 6th-magnitude denizen lies near the center of the Charioteer's pentagram and bristles with some 300 telescopic suns in an area of sky no larger than 21'. As with M35, it too has a dim (magnitude 8.2) and diminutive (7') companion, NGC 1907, which lies 33' to the south-southwest.

For years, M38 and NGC 1907 were candidates for a true physical pair, but recent studies have displaced NGC 1907 some 1,200 light-years beyond its brighter companion. But unlike M35 and NGC 2158, M38 and NGC 1907 share a similar age, around 400 million years.



RICHARD BEST

M38 in Auriga lies above its smaller companion, open cluster NGC 1907.

Now imagine this. While NGC 2158 only appears greatly smaller than M35 — both clusters are actually about 30 light-years in true physical extent — NGC 1907 is, in fact, much smaller than M38; while M38 spans some 20 light-years, NGC 1907 stretches across only half that diameter. Like NGC 2158, its stars are dim, but the brightest shine around 11th magnitude, so you may have an easier time resolving some of it.

Finally, there's one more thing to ponder. Studies of the motions of M38 and NGC 1907 through space suggest that while these clusters were born in different regions of the galaxy, their orbits have brought them together to experience a "flyby" close encounter.

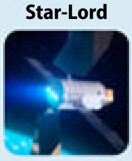
As always, send your thoughts to sjomeara31@gmail.com.

COSMIC WORLD

A look at the best and the worst that astronomy and space science have to offer. **by Eric Betz**

Cold as space — Supernova hot

Star-Lord



Congressman John Culberson tells NASA Administrator Charles Bolden to move beyond chemical propulsion and pave the way to Alpha Centauri. Bold, but maybe let them figure out Mars first?

D-day preppers

The United Nations task force charged with planning for space rock threats dissolves upon finishing a seven-year mission to form another group. Sadly, the best defense is still "Run!"

Wake up Philae!

Philae falls into indefinite slumber after a mission gone wrong in the European Space Agency's latest "Once upon a time" cartoon, tugging at the heartstrings of those eager for reply as communication lines reopen to Comet 67P's surface.

Farewell Spock

Astronaut Samantha Cristoforetti gives Leonard Nimoy a Vulcan salute and quotes *Star Trek*, tweeting "Of all the souls I've encountered … his was the most human." Cheers to a long and prosperous life!

ANALYTICAL MECHANICS ASSOCIATES/NASA (STAR-LORD); DON DAVIS/NASA (D-DAY PREPPERS); ESA (WAKE UP PHILAE); ESA (FAREWELL SPOCK)

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara.**

ASTRO**CONFIDENTIAL** BY KARRI FERRON

WHAT ARE WE LEARNING ABOUT "DYING" GALAXIES?

"Dying" galaxies are merely galaxies that are no longer forming new stars, so they also can be called "retired" galaxies. From modeling the stellar populations and star formation histories of several thousand nearby galaxies, my collaborators and I found that there are two main pathways through which galaxies retire. They either retire quickly (in less than 1 billion years), or they do so in a more sedate manner, taking 2 billion or more years before ceasing star formation completely.

Due to the accelerated evolution experienced by post-starburst galaxies (galaxies that have suddenly stopped forming stars), we realized that the smoking gun for the cause of such sudden evolution is more likely to be found in the predecessor population of galaxies, namely the "blue early-type galaxies."

To investigate the cause of sudden retirement, we probed the atomic hydrogen content of four blue early-type galaxies at different stages of evolution. Atomic hydrogen is an excellent tracer because it forms the initial gas reservoir from which stars form and is very sensitive to environmental effects and mild interactions that may not leave any signature on the stellar morphology of the galaxy.

We find that in the earliest stages, the gas is undisturbed. However, at later stages, we begin to see signs of an active supermassive black hole in the cores of these galaxies, the gas-to-stars ratio decreases significantly, and the atomic hydrogen begins to look disturbed and offset from the individual galaxy's main stellar body. Therefore, the cause for sudden retirement (or sudden death) is due to the removal of the entire gas reservoir from which stars form. As these galaxies are isolated, it is probable that the gas reservoirs have been blown out by the increasingly active central supermassive black hole in each galaxy, consequently forcing the galaxies into early retirement.

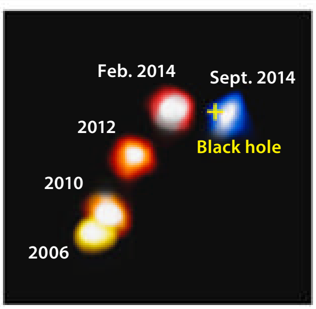
FAST FACT Feedback from a galaxy's central supermassive black hole is the likeliest reason for star formation shutting down.

O. Ivy Wong
Australian Research Council Super Science Fellow, ICRAR, University of Western Australia

COURTESY O. IVY WONG

ASTRO**NEWS**

ASTEROID SPIN. The Keck Observatory found the solution to mysterious "active" asteroids that mimic comets with tails by ejecting dust. The space rocks were measured rotating fast enough to throw off material and trigger fragmentation.



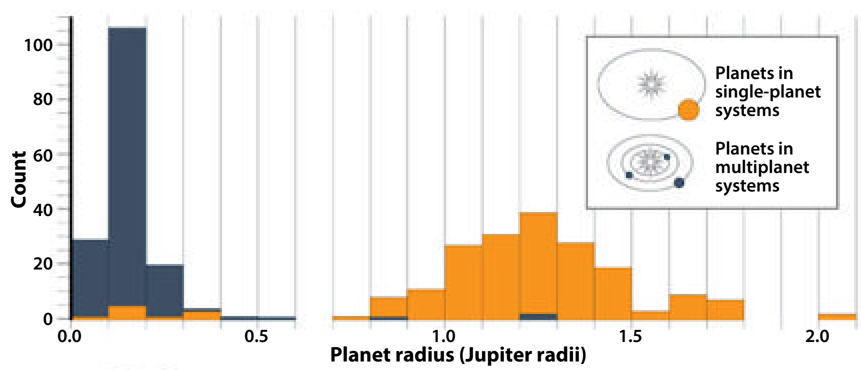
ESO/A. ECKART

Galactic core dust cloud surprises astronomers

BLACK HOLE SURVIVOR. Observations made with the Very Large Telescope are providing scientists' best look at the seemingly free-floating gas cloud G2, which in 2012 astronomers predicted would be torn apart by the Milky Way's supermassive black hole as it approached the galactic center. G2 did make its closest approach in May 2014 as predicted, but, surprisingly, it wasn't stretched by the black hole's gravity and remains intact, as shown in this composite infrared image (with red colors indicating the object is moving away from us and blue showing its movement toward us). As a result, astronomers now think G2 must surround a dense object with a massive core. — **K. F.**

HOT JUPITERS ARE LONELY

SIBLING RIVALRY. Looking only at close-in exoplanets (orbiting their stars within five days), it's easy to see that small planets like having neighbors — that is, they tend to be found in multiplanet systems. But hot Jupiters reside mostly in single-planet systems, probably because they form farther away and kick out their siblings on their migration in toward their stars.



ASTRONOMY: KOREY HAYNES AND ROEN KELLY

FAST FACT As of April 15, scientists have discovered 465 systems with multiple planets, 466 if you count our own solar system.

RED PLANET BLUES. Mars once had enough water to cover its entire surface to a depth of 450 feet (140 meters) but lost almost all of it to space. NASA/GSFC

Ancient Mars was more hospitable

NASA astronomers discovered that the Red Planet once had 6.5 times the amount of water presently locked in its polar ice caps, which probably covered a surface area in its northern hemisphere slightly larger than Earth's Atlantic Ocean. The results were published in the journal *Science* on April 10. Meanwhile, scientists from Brown University submitted to the *Journal of Geophysical Research: Planets* that now dry Jezero Crater was the site of two separate watery events in Mars' past. Jezero Crater is on the short list of possible landing sites for the 2020 Mars rover, and the discovery of a water-rich history only makes the site more intriguing.

But water isn't the only requirement for life found on the Red Planet. As published in the April 7 *Proceedings of the National Academy of Sciences*, the Curiosity rover discovered nitrates, a biologically useful form of nitrogen. In contrast to Earth's nitrates, meteorite impacts probably formed the martian version. Nonetheless, their existence is further evidence of Mars' past habitability. — **K. H.**

BY KARRI FERRON

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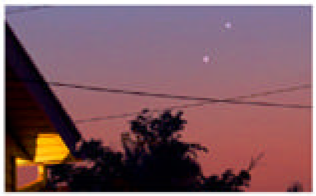
The Sky this Week

A daily digest of celestial events

Only have a little time each night to enjoy the wonders of the cosmos and want something quick and easy to observe? Look no further than Astronomy.com's "The Sky this Week." Written by Senior Editor Richard Talcott, this popular section highlights one or two sky events each night that you can observe through binoculars or a small telescope — many with just your naked eyes. In 10-day increments, learn when and where to spot each planet, the best meteor showers, bright comets and asteroids, the occasional double star, a few deep-sky objects, and more. Each daily entry offers essential details of the event and how to locate it in your sky. Many of the week's most significant occurrences also feature an image or an *Astronomy* magazine star chart to help you witness what's going on overhead. See what's on tap for tonight at **www.Astronomy.com/skythisweek**.



JOHN CHUMACK

JOHN A. DAVIS

OBSERVING TOOLS

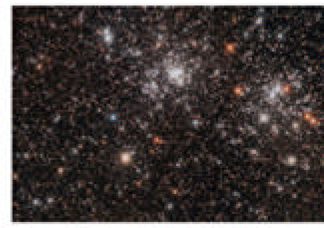
Summer observing videos

Find out where to start your summer sky exploration with Astronomy.com's seasonal observing videos. In one, Senior Editor Richard Talcott explores the big events of the summer, including a stunning close visual encounter between Venus and Jupiter. In another, Senior Editor Michael E. Bakich focuses on warm-weather objects you can see through a small telescope, such as the Hercules Cluster (M13). And finally, Editor David J. Eicher shares 10 of his favorite summer deep-sky objects, including the Dumbbell Nebula (M27). Check out all three videos at **www.Astronomy.com/seasons**.

COMMUNITY

Reader Photo Gallery

Browse beautiful astroimages like this one of the Double Cluster (NGC 869 and NGC 884) by Steve Pastor. Submit your own images at **www.Astronomy.com/readergallery**.



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PLUTO

The gray surface of Pluto's largest moon, Charon (foreground), stands in contrast to the planet's reddish-brown coloring. Scientists eagerly await the first close-up images of these worlds from the New Horizons spacecraft. RON MILLER FOR *ASTRONOMY*

Up close and personal

Cold, dark, and as yet unexplored, distant Pluto will finally bask in the spotlight when the New Horizons spacecraft flies past this July. **by S. Alan Stern**

This July, NASA's New Horizons spacecraft will complete the historic first reconnaissance of the Pluto system — and with it, the first exploration of a Kuiper Belt planet and its attendant moons. The battle to get such a mission approved and funded stretched across 14 years, from 1989 to 2003, but succeeded on the richness of the groundbreaking science that would stem from exploring the Pluto system and the Kuiper Belt for the first time. Started by a small band of young scientists, this quest involved a decade of mission studies that led powerful NASA advisory committees and, ultimately, the National Academy of Sciences to recommend the mission as a top priority.

How did Pluto, once considered to be a faraway footnote in planetary science, become transformed into a centerpiece in the quest to understand the formation and evolution of our solar system? The answer is a story about revolutions in technology and revolutions in understanding both the basic architecture and population of our planetary system. The story began in early 1905 and will culminate this year, in July 2015.

S. Alan Stern *of the Southwest Research Institute in Boulder, Colorado, is a planetary scientist and the principal investigator of New Horizons.*

A planet ahead of its time

Boston-born astronomer Percival Lowell initiated the search for a planet beyond Neptune in 1905, a year before the birth of the person who eventually found it, Clyde Tombaugh. Tombaugh discovered Pluto on photographic plates taken in 1930 at Lowell Observatory in Flagstaff, Arizona. Yet it was so far away, small, and faint — 41 times Earth's distance from the Sun, less than 0.1 arcsecond in diameter, and magnitude 15.1 — that it was far beyond the technology of the times to learn much about it.

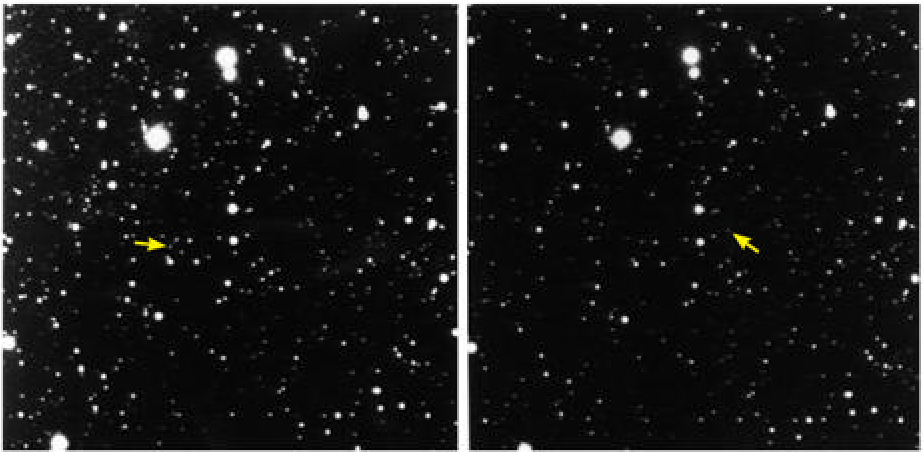
In fact, with 1930s technology, all anyone could determine about Pluto was its orbit and color. Planetary scientists could not measure its size, detect its atmosphere, see its satellites, and therefore could not discern its interior density. Even the planet's rotation period could not be determined reliably until the 1950s, two decades after Pluto was discovered.

Despite the paltry facts known about Pluto in the 1930s and '40s, speculation about its origin ran rampant. For example, when astronomers determined that its orbit crossed inside Neptune's, some speculated it was an escaped satellite of the giant planet. Others thought it might be a super-Ceres, a giant asteroid somehow ejected to the distant reaches of the solar system. Still others, including prescient astronomers like Fredrick Leonard and Kenneth Edgeworth, suspected it was part of a larger

Clyde Tombaugh discovered Pluto on February 18, 1930. Here, he stands at the door of the building that housed the 13-inch discovery telescope at Lowell Observatory. LOWELL OBSERVATORY

population of yet-to-be discovered bodies beyond the giant planets. Unfortunately, the data available then offered no clue as to which hypothesis might be correct.

Planetary science in the middle decades of the 20th century continued to be stymied



These are small sections of the photographic plates Clyde Tombaugh used to discover Pluto. The arrows mark the distant world's changing position relative to the background stars over a six-day period in January 1930. LOWELL OBSERVATORY

by the primitive technology of the time. None of the modern tools of planetary science — such as sensitive CCD cameras, powerful computers, and spaceflight — were available. So Pluto remained a mysterious and puzzling footnote to an otherwise grand-design architecture of our solar system then "known" to consist of four small, inner rocky planets, four outer gas giant planets, a wide variety of comets and asteroids, and misfit Pluto.

The modern era begins

The first big observational breakthroughs that illuminated our knowledge of the Pluto system began in the mid-1970s. This veritable dam break of news commenced in 1976 when University of Hawaii astronomers Dale Cruikshank, Carl Pilcher, and David Morrison discovered methane ice on Pluto. The finding surprised scientists in part because they quickly realized that at Pluto's temperature, the surface methane should turn directly from ice to gas and create a tenuous atmosphere around the planet. But the methane ice also was surprising because researchers knew of no other solid body in the outer solar system besides Saturn's moon Titan that had methane on its surface. Water ice was the norm. What was up with Pluto?

Scientists barely had time to digest this discovery before they made a second major breakthrough. In 1978, U.S. Naval Observatory astronomers James Christy and Robert Harrington discovered a satellite of Pluto, which Christy named Charon in part to honor his wife, Charlene. Startlingly, Charon turned out to orbit with the same period as Pluto's rotation, meaning it resides in a so-called synchronous orbit above Pluto and implying that strong tidal forces have affected the system's evolution.

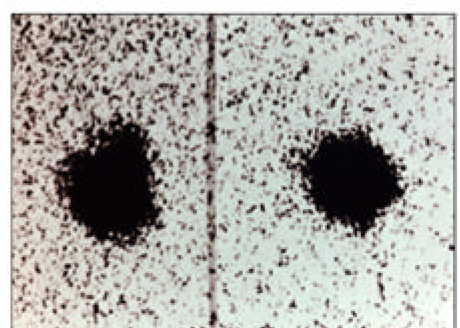
Within months of Charon's discovery, astronomers realized that the moon's orbit would soon turn edge-on to Earth and the pair would undergo mutual occultations. The search for these began in the early 1980s and culminated in late 1985 when University of Texas astronomer Rick Binzel detected the first mutual event. Between 1985 and 1990, planetary astronomers around the world observed a long series of these occurrences.

From these studies, scientists derived accurate sizes and surface albedos (the fraction of light a body reflects) of Pluto and Charon for the first time as well as crude albedo and composition maps of the surfaces of both worlds. The results also showed that Charon's surface is unlike Pluto's. The moon is about 60 percent as reflective as Pluto, has none of Pluto's red color, and is covered in water ice with no trace of methane.

Another notable result derived from the mutual events came from an accurate measure of the masses of Pluto and Charon, which, when combined with their sizes, yielded densities for both bodies. This showed that Charon consists primarily of water ice, with its rocky component limited to perhaps 40 to 50 percent of the body's mass. But the big surprise was Pluto's density, which turned out to be just over two times that of water ice, meaning it isn't the icy world scientists long had expected it to be. Instead, Pluto contains about 70 percent rock by mass. You can't judge this book by its icy cover. No one expected the outermost planet to be rocky rather than icy.

The mutual events also revealed the angular momentum of the Pluto-Charon system. Planetary scientist William McKinnon of Washington University in St. Louis and others used these results to show that the system, a binary with a mass ratio of about 11 to 1, could not have formed except by a collision of some former planet-sized body with Pluto.

As the 1980s progressed, our understanding of Pluto advanced as researchers studied the light of distant stars when Pluto passed in front of them. Massachusetts Institute of Technology scientist James Elliot and his colleagues used one such stellar occultation to confirm that Pluto has an atmosphere. Further occultation observations yielded evidence for hazes



U.S. NAVAL OBSERVATORY

U.S. Naval Observatory astronomers James Christy and Robert Harrington discovered Charon, Pluto's largest moon, in 1978. It appears as a slight elongation on these images of Pluto.

Pluto and New Horizons through the years

1905
Percival Lowell launches a search for "Planet X."

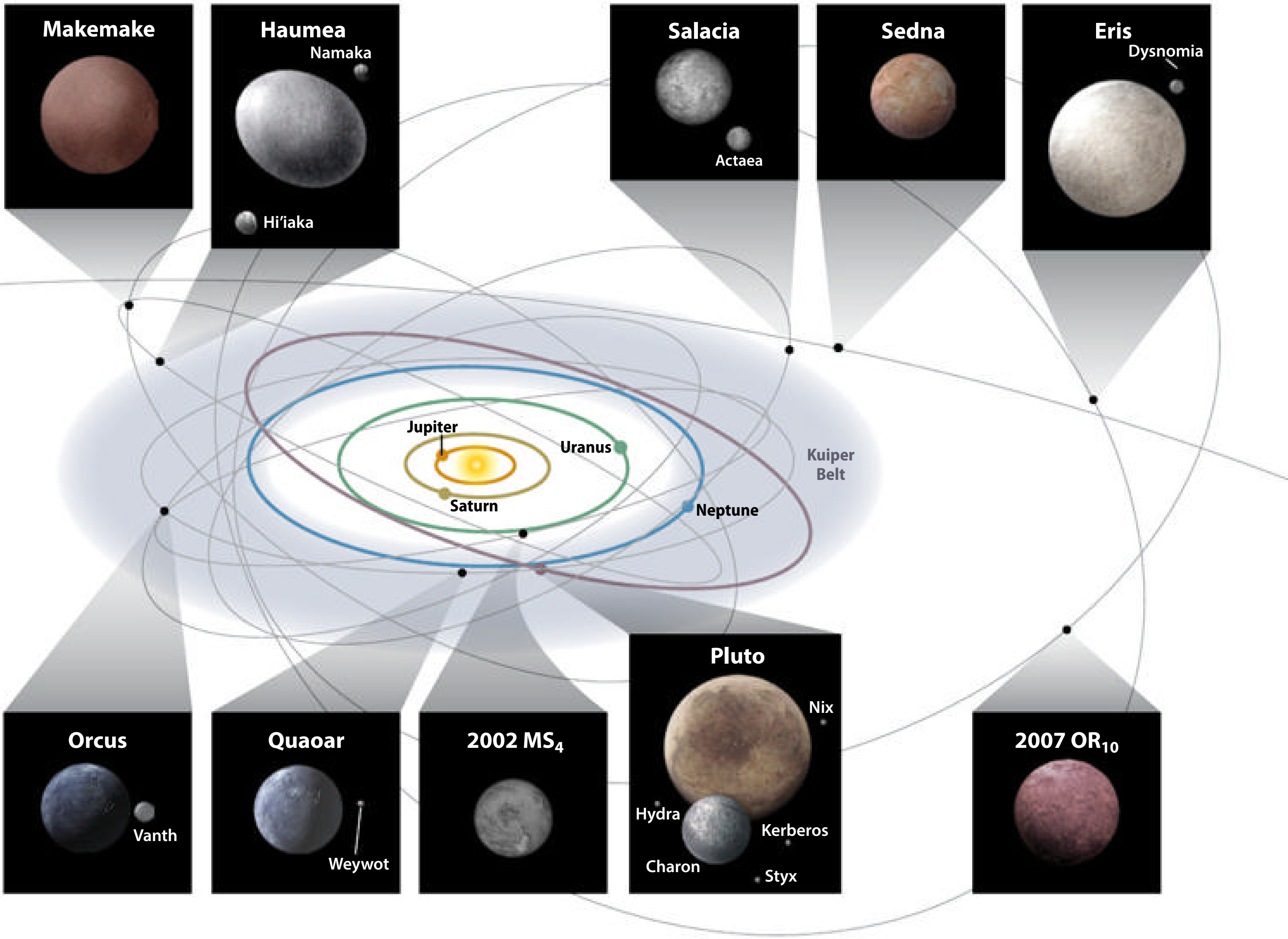
1930
Clyde Tombaugh discovers Pluto from Lowell Observatory.

1950
Gerard Kuiper proposes the existence of a large belt of icy objects beyond Neptune.

1976
Dale Cruikshank, Carl Pilcher, and David Morrison discover methane ice on Pluto.

The biggest objects beyond Neptune

Pluto and Eris are the largest trans-Neptunian objects, though several others come close. Pluto resides in the disk-shaped Kuiper Belt, a region containing thousands of icy bodies. *ASTRONOMY*: ROEN KELLY



or a complex temperature structure in Pluto's atmosphere, signs of turbulence and winds in the upper atmosphere, clues indicating Pluto's blanket of air has a significant escape rate, and inklings of other atmospheric constituents beyond methane.

By the dawn of the 1990s, the Pluto-Charon system was becoming a surprisingly complex pair that was attracting attention for exploration. Toby Owen of the University of Hawaii and collaborators discovered nitrogen ice on Pluto and determined that nitrogen dominates both Pluto's surface and atmosphere.

Others, including myself, later used the Hubble Space Telescope and found evidence for a polar cap on Pluto. And Lowell Observatory astronomer Marc Buie cleverly fused Hubble and old ground-based data to establish that the planet's surface appearance has changed on a massive scale since its discovery.

Interest in Pluto accelerated after Voyager 2 encountered Neptune in 1989. Images revealed that Neptune's moon Triton — a size, density, and compositional cousin of Pluto as well as a former planet that had once orbited the Sun on its own — is geologically active and sports surface geysers!

As amazing as the Pluto-Charon pair was then becoming, the most important revolution in our knowledge about this system was still to come.

1978 James Christy and Robert Harrington discover Pluto's largest moon, Charon.

1985 A series of mutual occultations between Pluto and Charon begins, allowing scientists to measure the objects' diameters — and much more.

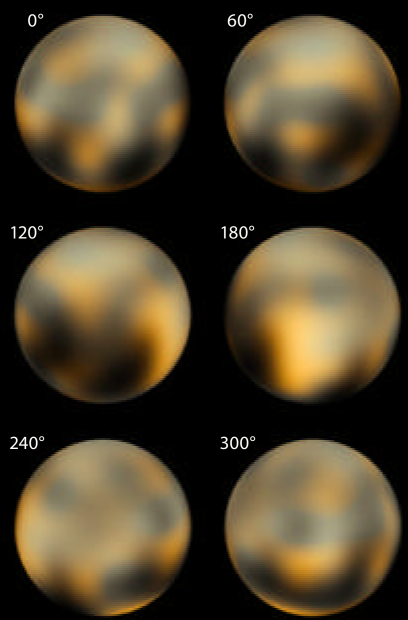
1987 Marc Buie and Robert Marcialis lead teams that discover water ice on Charon.

1988 James Elliot and colleagues discover Pluto's thin atmosphere.

1992 Toby Owen and colleagues discover nitrogen and carbon monoxide ices on Pluto.

1992 David Jewitt and Jane Luu discover 1992 QB_1, the first Kuiper Belt object (not counting Pluto).

Pluto's surface



Hubble Space Telescope images show color and brightness changes across Pluto's icy surface, though even Hubble can't resolve features smaller than a few hundred miles across. The center points of these hemispheric views are evenly spaced across the planet's globe. NASA/ESA/M. BUIE (SwRI)

The revolution of the Kuiper Belt

Astronomers long puzzled over the apparent lack of context for Pluto, orbiting alone and largely beyond Neptune — seemingly a misfit in the solar system.

That said, mid-20th-century planetary science giant Gerard Kuiper, following on ideas Leonard and Edgeworth had pioneered, made a convincing case in 1950 that Pluto might be the brightest of a vast cohort of similar planets and smaller bodies orbiting in the "trans-Neptunian region." The idea led to several searches, but the technology of the times — based on low-efficiency photographic detectors and requiring painstaking manual comparison of images — prevented discoveries of other bodies.

All that changed in 1992 when University of Hawaii astronomers David Jewitt and Jane Luu discovered an object called 1992 QB_1, the first sighted partner to Pluto orbiting beyond Neptune. Although scientists estimated it to be 10 to 30 times smaller than Pluto's 1,485-mile (2,390 kilometers) diameter, QB_1 unleashed a torrent of discoveries almost immediately. In 1993, observers found four more such objects. In 1994, 10 more turned up. By the late 1990s, researchers had discovered almost 1,000 bodies. Pluto's context was now clear: It was not a misfit; it simply had been the first and brightest of a vast population of solid bodies ranging from roughly 60 to more than 600 miles (100 to over 1,000 km) across orbiting beyond Neptune.

This powerful discovery led to a fundamental redrawing of our map of the solar system, adding a third zone beyond the terrestrial and giant planets — the so-called Kuiper Belt.

But relegating the giant planets to the middle zone of the solar system and providing a context for Pluto was only part of the paradigm shift ushered in by the Kuiper Belt. As the 1990s and then the 2000s progressed, it became clear that the Kuiper Belt had much more to teach us than just Pluto's true context and the existence of a third zone to the planetary system.

Observations of the Kuiper Belt also revealed that Pluto-class planets were common out there, as were satellites of these worlds. In the end, the census of Kuiper Belt planets outnumbers both the terrestrial and giant planets! Pluto is in big company. Who are the misfits now?

Additional discoveries showed a wide diversity in the newly discovered planets of the Kuiper Belt — those worlds big enough to be rounded by self-gravity. Some have water ice surfaces, but some sport more exotic surface volatiles (those compounds that vaporize at a relatively low temperature), such as methane and nitrogen, as on Pluto. Many have moons — some large relative to their primaries — again like Pluto. Some are red, like Pluto, but others are neutrally colored (gray), like Charon. Some have densities that point to mostly icy interiors, while others have densities so high they essentially must be all rock. Although scientists had argued for the existence of a third zone to our planetary system and the presence of many small planets there before they found the Kuiper Belt, no one predicted the degree of diversity in the Kuiper Belt population. It was, and remains to this day, surprising.

The discovery of the Kuiper Belt was a revolution that shook many of our formerly primitive notions of the architecture and content of our solar system. Moreover, it revealed a rich wonderland of exotic new worlds and sparked debates on the nature of planethood.

And it so impressed the scientific community with its importance to the understanding of solar system origins and its potential for groundbreaking new discoveries that it caught the attention of the National Academy of Sciences. The academy called on NASA to rocket the funding priority for a mission to explore the Pluto-Charon system and smaller bodies in the Kuiper Belt to the top of the queue for new missions.

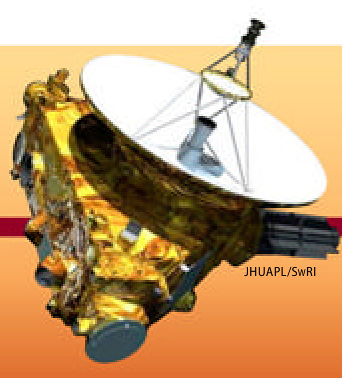
Wonderland Pluto

Meanwhile, as the Kuiper Belt revolution was unfolding, so was our knowledge about the Pluto system.

In the 2000s, observers saw Pluto's atmospheric pressure double, then triple. No one is exactly certain why, even today. Then researchers found that Charon has ammonium hydrates (compounds of ammonia and water) on its surface in addition to water ice. Moreover, scientists learned that Charon's surface water ice has a crystalline structure that indicates it must have been deposited recently. But how — could Charon be active?

Almost simultaneously, in 2005, an observing team led by Hal Weaver at Johns Hopkins University, which I was a part of, was granted Hubble time to search for Pluto satellites. In one afternoon, Hubble detected not one but two moons orbiting beyond Charon in the same orbital plane. We named them Nix and Hydra. In 2011 and 2012, members of our team led by Mark Showalter of the SETI Institute found two

1994
S. Alan Stern and colleagues discover surface details on Pluto in Hubble Space Telescope images.



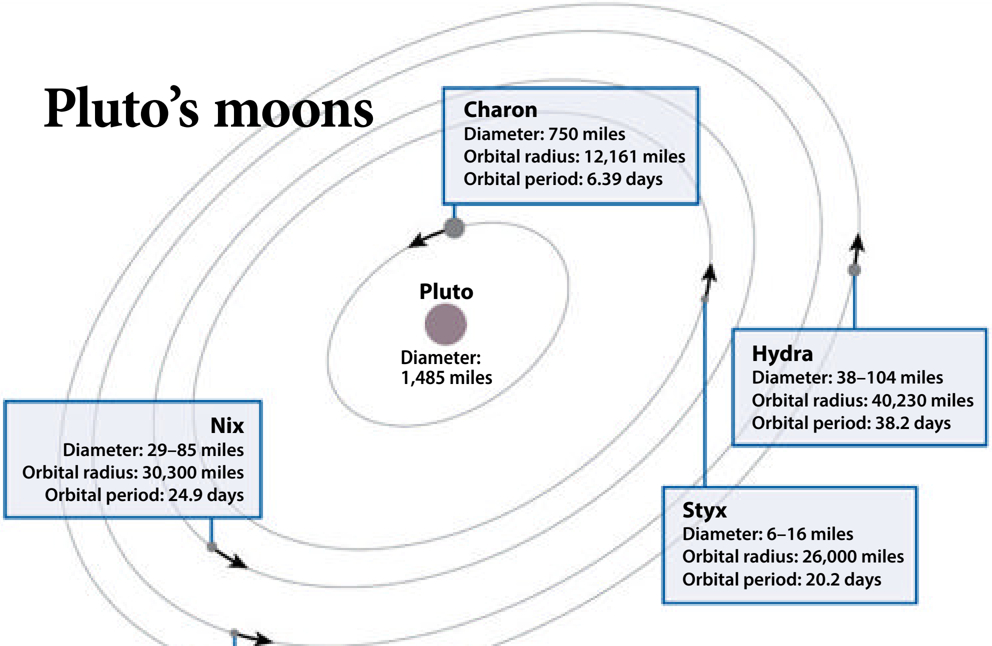
JHUAPL/SwRI

2005
Hal Weaver and S. Alan Stern lead a team that discovers Pluto's moons Nix and Hydra.

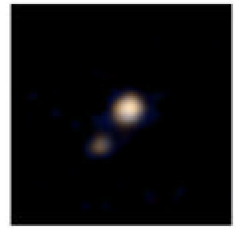
2006
New Horizons launches from Cape Canaveral, Florida.

2007
New Horizons flies past Jupiter, receiving a gravity assist that allows it to reach Pluto more quickly.

Pluto's moons



Close-in Charon is by far the planet's largest and best-studied satellite. Even with New Horizons on Pluto's doorstep, some basic facts about the outer four moons remain sketchy. (To convert miles to kilometers, multiply by 1.61.) *ASTRONOMY*: ROEN KELLY



NASA's New Horizons spacecraft captured this view of Pluto (center) and Charon on April 9 from a distance of 71 million miles (115 million kilometers). NASA/JHUAPL/SwRI

more even smaller satellites, later named Styx and Kerberos. Pluto now has five known moons, and many of us expect to find more when we see the system up close.

Although the new moons display neutral colors like Charon, no one knows if their albedos are similar to Charon's because we haven't pinned down their sizes. But thanks to Showalter, we do know that at least one and possibly more of these small satellites are apparently tumbling chaotically. And, puzzlingly, their orbits seem to be uniformly close to, but not precisely in orbital resonances with Charon. (Charon completes about three orbits for every one of Styx; four for Nix; five for Kerberos; and six for Hydra.) Why so close, yet so far?

Also in the 2010s, Bob Johnson of the University of Virginia and O. J. Tucker of the University of Michigan showed that Charon can siphon gas off Pluto's atmosphere in a process that is likely to create a wispy atmosphere of its own.

Every time we look at the Pluto system with better tools, it gets more complex, more nuanced, and even more bizarre. Well, hang on to your hat because the best tool of all for Pluto exploration was launched in 2006 on a decadelong journey to explore it in 2015.

Enter New Horizons

In the coming weeks, NASA's New Horizons mission, which I lead as principal investigator, will reconnoiter the Pluto system. Built to accomplish the objectives set forth by the National Academy of Sciences' 2003 Decadal Survey in Planetary Science, New Horizons is now on final approach to Pluto after a 3-billion-plus-mile (5 billion km) journey from Earth.

The spacecraft started observing the Pluto system in mid-January. It has been taking images, measuring the dust and charged-particle environment near Pluto, and refining the planet's orbit around the Sun ever since.

Close-approach observations began in June and culminate July 14 with a deep dive that reaches closest approach about halfway between Pluto and the orbit of its closest known moon, giant Charon. During approach, at closest distance, and then as it recedes, the spacecraft will capture thousands of images, millions of spectra, detailed measurements of the local plasma environment, and even sample gases coming off Pluto's atmosphere.

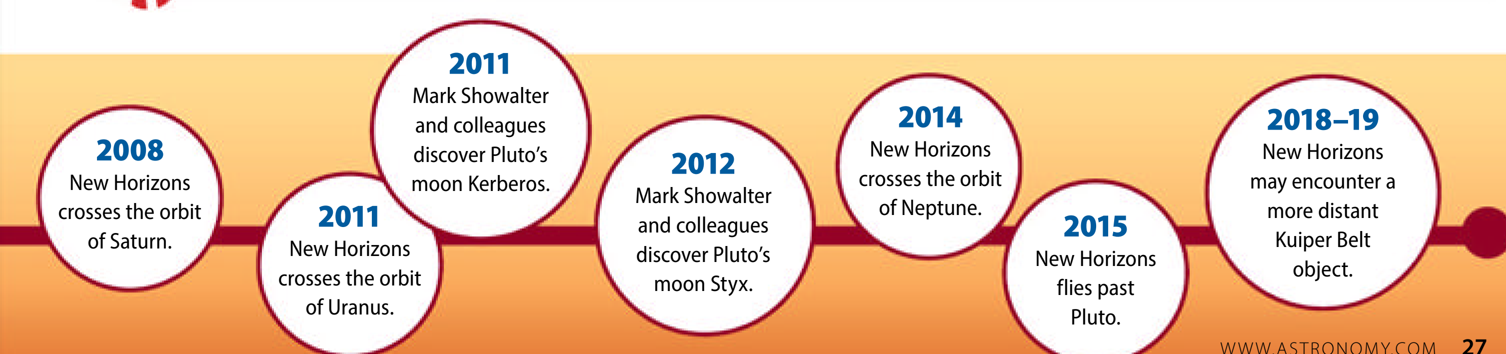
New Horizons will obtain color and panchromatic maps of Pluto and each of its known moons. It will search for new satellites and even rings. It will study the compositions of all six known bodies in the system. And at Pluto, it also will assay the composition, structure, and escape rate of the atmosphere. The spacecraft will make surface temperature maps of both Pluto and Charon, and it will look for an atmosphere around Charon and an ionosphere around Pluto.

By the time New Horizons finishes returning all its observations to Earth in late 2016, Pluto will be transformed from a world known only from afar to one with better data sets than we have ever had on a newly reconnoitered planet.

Digesting that data may take a decade, during which we hope that New Horizons can fly on to explore one or perhaps two smaller, more primitive objects in the Kuiper Belt up to 2 billion miles (3 billion km) farther still from the Sun.

Astronomers didn't discover the solar system's third zone until the 1990s, but by the mid-2000s, humankind had dispatched a sophisticated probe to explore it. Today, in the 2010s, we are on the cusp of that exploration. Buckle up your seat belts — from everything we've learned so far about the Pluto system, we are going to be in for quite a ride!

FOR DETAILS ON THE COMPLEX CHOREOGRAPHY NEW HORIZONS MUST EXECUTE AT PLUTO, VISIT **www.Astronomy.com/toc.**



Imagine the science and the safety we could achieve by finding space rocks like Chelyabinsk before they enter our atmosphere. **by Mark Boslough**

In search of DEATH PLUNGE ASTEROIDS

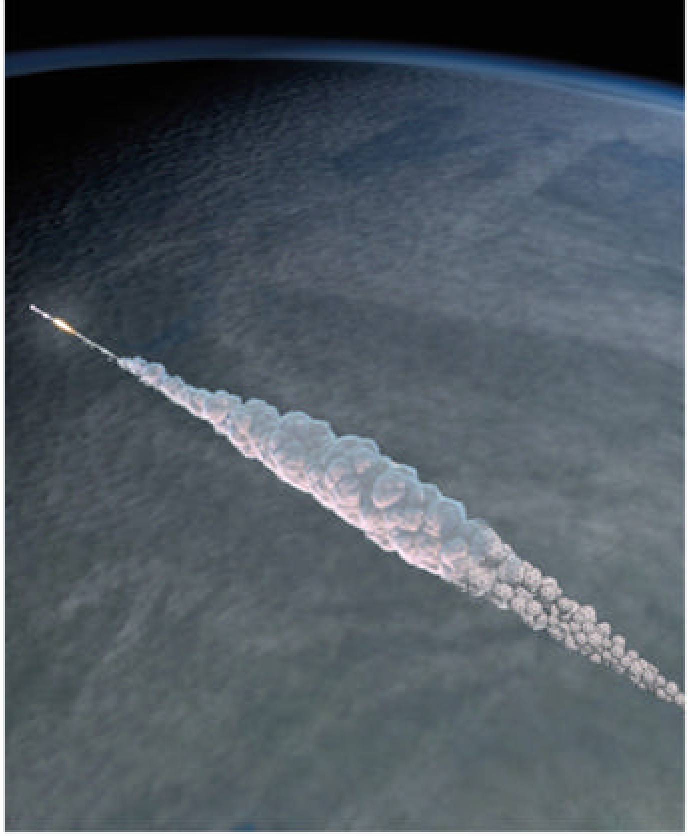
The 2013 meteor that exploded over Chelyabinsk in Russia was captured in images only by those fortunate enough to be looking up at the right moment. Imagine what we could have seen with advanced warning. MARAT AKHMETALEYEV

In an alternate world with a more advanced asteroid search campaign, astronomers could have prepared all night for the big impact. OSHIN D. ZAKARIAN

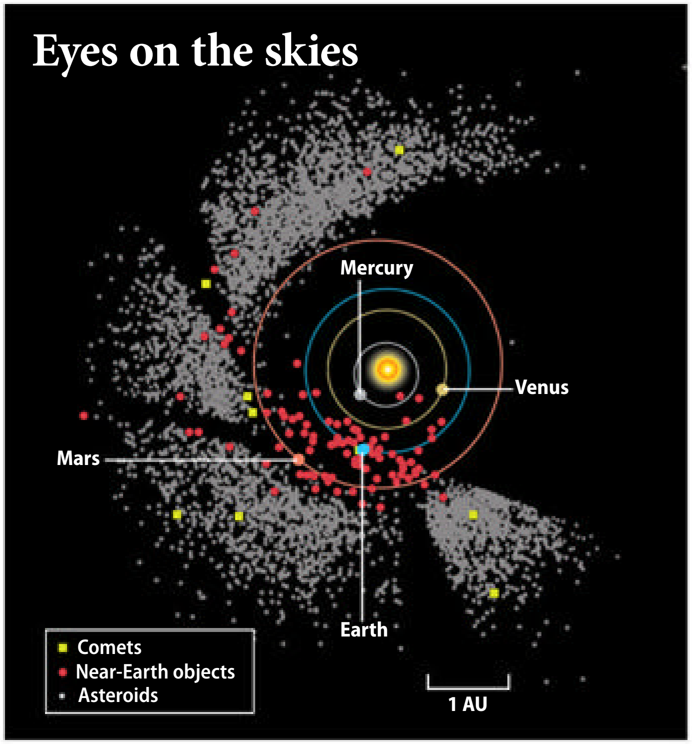
MUCH TO THE DELIGHT of scientists and technicians, the frigid sky over the snow-covered Siberian fields and villages remained clear as dawn approached. The February stars put on a dazzling show as they revolved about Polaris, higher in the sky than many of the foreign visitors were used to seeing it. The frequency of sporadic meteors increased as the night grew long, as if providing a warm-up act.

Charter flights were already in the air, filled with business tycoons and celebrities, and rumor even had it that Russian President Vladimir Putin was on one. The planes could be seen in all directions except in the special airspace dedicated to cooperative research flights by the Russian Federal Space Agency, the European Space Agency, and NASA, and in the restricted airspace directly beneath the asteroid's projected path. In order to keep light pollution from interfering with the observations, the nearby city of Chelyabinsk was in blackout. Everyone waited at the ready for the meteor event of the century.

This is a fictional account of what might have happened February 15, 2013, if we had been a decade further along in our efforts toward asteroid discovery and planetary defense. An array of powerful space-based infrared survey telescopes (such as the proposed NEOCam or Sentinel Mission), combined with dedicated ground-based telescopes (such as ATLAS and LSST, both



The meteor explosion pictured here is the result of a 3-D simulation by the author. By modeling such events, he and colleagues can compare them to past and future airburst observations in order to learn more about both their progenitor asteroids and the power they bring with them into Earth's atmosphere. M. BOSLOUGH/B. CARVEY/A. CARVEY



In NEOWISE's first six months, it discovered dozens of new near-Earth objects and observed many more. Each gray dot represents an asteroid, most of which orbit in the main belt between Mars and Jupiter. Yellow squares represent comets, while red circles indicate near-Earth objects that orbit within 1.3 astronomical units (1 AU is the average Earth-Sun distance).

currently under construction) might have been able to warn us of the 65-foot-wide (20 meters) asteroid that exploded over Russia, causing damage and alarm. We have pieced together the asteroid's story from recovered fragments and serendipitous dashboard-camera footage. But imagine instead how the events near Chelyabinsk might have unfolded if an advanced detection system had already been in place.

Getting ready

In that fictional world, by the time the southeastern sky began to glow with faint hints of light, scientists had been up all night calibrating and testing their equipment. The weeks of planning meant they had time to spare, and they spent it photographing the stars, drinking coffee or tea, fidgeting, and (except for the North Americans) smoking cigarettes. High-definition cameras, telescopes, radiometers, radar dishes, spectrometers, and optical pyrometers all pointed at a spot above the eastern horizon. The instruments were mounted on gimbals so they could rapidly slew at just the right rate to track the fireball. Even with advanced warnings, there would be no second chance.

Researchers already had deployed arrays of seismometers, geophones, microphones, infrasound detectors, microbarographs, anemometers, and dust collectors. Now, just before sunrise, they launched drones and balloons to get precise readings of atmospheric conditions and to record the characteristics of the blast wave in three dimensions.

It wasn't just the scientists who were recording. Production company film crews were on the scene, including multiple IMAX cameras on the ground and in the air. This would be the best-documented natural event in history because it was the best ever predicted.

Since its discovery a month earlier by two new space-based infrared telescopes, designed and launched for just this purpose, the asteroid had swept close enough to be observed by ground-based optical telescopes. In the last few days, radio telescopes at Goldstone and Arecibo were able to join the effort, and last night even amateurs made sightings. Its reflectance spectrum suggested that it was an ordinary chondrite, rocky and unevolved. Radio telescopes estimated that it was between 17 and 20 meters in diameter.

There was still a lot of uncertainty about its mass because no one knew whether the asteroid was a single rock or a porous rubble pile. But it couldn't be much more than 12,000 tons even if it were fully dense. Meticulous observations had characterized the asteroid's orbit so precisely that scientists were predicting the time of impact to the nearest second, the location to the nearest kilometer, and the entry speed to be exactly 12 miles (19 kilometers) per second. It would almost certainly explode in the atmosphere, and simple physics determined the energy of the explosion: about a half megaton of TNT.

Despite being 30 times bigger than the explosion that destroyed Hiroshima, that estimate had come as a great relief to the residents of Chelyabinsk. A month earlier, a much bigger explosion had not been ruled out, and there had been contingency plans to evacuate the city's million residents. A half-megaton explosion high in the sky can be powerful enough to blow out windows and do damage, but officials determined "shelter in place" and the Cold War "duck and cover" drill sufficient to protect city residents 25 miles (40km) to the north. On the other hand, more local villages were still at risk from falling meteorites, which could be fatal, and residents were advised to leave the area.

Mark Boslough *is a principal member of the technical staff at Sandia National Labs with a focus on national security applications.*

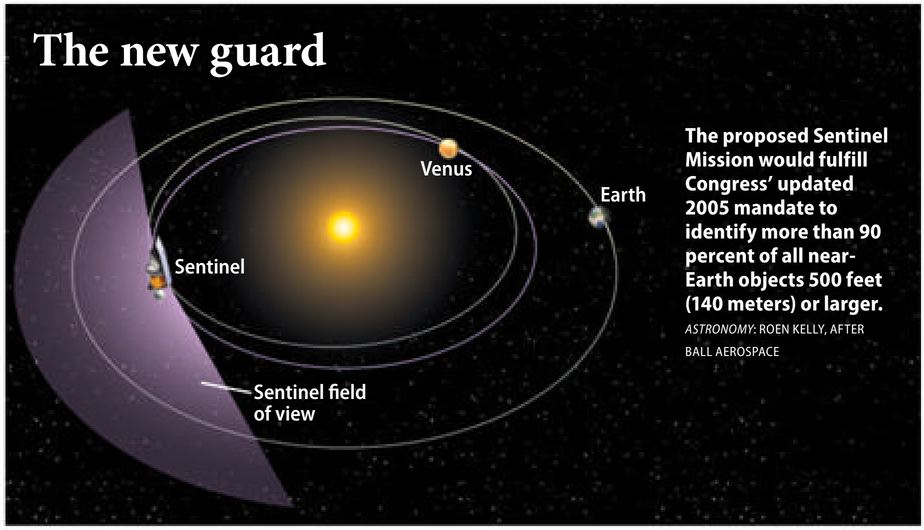
The show begins

About 15 minutes before sunrise, powerful radar started receiving reflections from over the horizon while the asteroid was still thousands of kilometers above the Pacific Ocean. Twelve minutes later, it had traversed China and Kazakhstan. A few minutes after that, the Russians fired an array of smoke tracer sounding rockets, like fireworks, into the sky along both sides of the asteroid's trajectory, to measure the shock wave like in the good old days of Cold War atmospheric nuclear testing. As the asteroid approached the border into Russia, still more than a hundred kilometers up, sensitive infrared detectors and radiometers locked onto it.

As the clock ticked, events accelerated. The asteroid was coming in hot — 19 km/s is 42,000 mph, or Mach 56. It was moving mostly sideways, descending only 1 kilometer for every 3 kilometers of horizontal flight. That was lucky for everyone. The scientists had more time to gather data, the tourists had a longer show, and the locals were spared the damage that a steeper entry angle would have inflicted by carrying the energy downward toward the villages.

The asteroid rammed into the air faster than the molecules could get out of its way. Like a snowplow, it scooped them up, compressed them, and carried them along as a high-temperature plasma that pushed a shock wave ahead of it and then wrapped around it in a pencil-thin wake. After a few seconds, the asteroid descended into air that was thick enough to be opaque when compressed, and hot plasma grew bright enough to see with the human eye.

Scientists whooped as their trackers started tracking and their high-speed cameras started whirring. Cheers went up from the open fields in Chelyabinsk, where spectators watched at safe distances from window glass and anything that could fall. Movie stars in private jets clinked their champagne glasses together. Villagers who refused to evacuate hugged one another and hoped that a meteorite would fall near them, but not on them.



The proposed Sentinel Mission would fulfill Congress' updated 2005 mandate to identify more than 90 percent of all near-Earth objects 500 feet (140 meters) or larger. *ASTRONOMY*: ROEN KELLY, AFTER BALL AEROSPACE

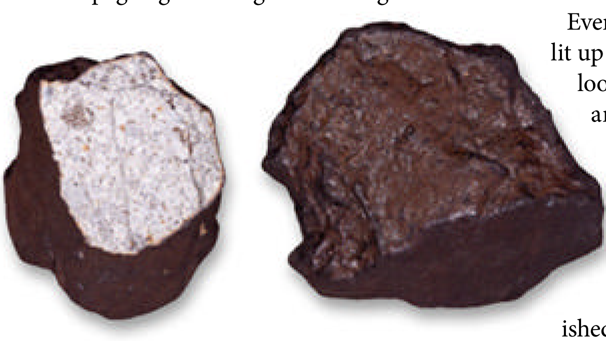
But the show had just started. For the next 10 seconds, the asteroid grew much brighter as it forced its way through the air, compressing it into an ever hotter and denser plug of ionized gas. The asteroid's core was as yet undisturbed, the pressure in the thin upper atmosphere too small to deform or break solid rock. But the heat of entry penetrated the surface of the rock, removing material that was immediately vaporized and swept away into the wake.

As the excitement continued, the asteroid reached a critical altitude at which pressure from the air finally exceeded its strength, and the core began to fracture. This led to a mutually reinforcing cascade of processes: The fragmentation meant exponentially increased surface area and therefore exponentially increased drag forces, and the increased drag forces caused further fragmentation. When the fragments became small enough, they vaporized entirely, kinetic energy converting to explosive energy in the spectacular climax of the asteroid's death plunge.

Even as the tremendous explosion lit up the sky, a small fragment that looked like a mere spark popped out and continued downrange to the west. Infrared and radar trackers were able to follow it for several more seconds. They calculated its impact point before it even touched the ground.

Before the explosion had finished fading from sight, the charter flights and private jets were already turning to flee the scene. They were not supersonic and could not outrun the blast wave, but the farther they got, the weaker it would be. The first to feel the blast were observers near the villages at ground zero, directly beneath the main explosion. It only took about a minute. Ground arrays provided a precise pattern of surface effects, which would be invaluable for estimating risk and planning for future events. Another minute later, the blast reached Chelyabinsk. It did limited damage because most residents and businesses had heeded warnings and boarded up their windows, saving up to 1 billion rubles ($33 million) in potential damages.

Within only a few more minutes, a helicopter landed next to a hole in the ice of the frozen Lake Chebarkul, the location pinpointed by tracking data of that small spark, actually the largest remaining piece of the meteorite. Arrays of acoustic sensors had located many of the other large meteorites that fell on solid ground, and meteorite collectors — both professional and amateur — raced to their locations. Laboratories were at the ready to measure short-lived radioisotopes, and the analysis work proceeded swiftly, according to careful plan.

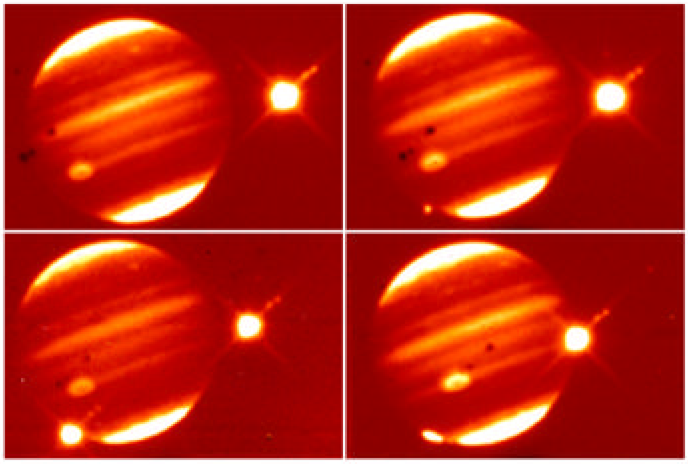


While some fragments from the Chelyabinsk meteor were recovered quickly, others took months to locate and retrieve, partially due to incomplete information regarding the unexpected meteor and its trajectory. DIDIER DESCOUENS

Back to reality

The description in this story of the Chelyabinsk asteroid itself is scientifically accurate to the best of my knowledge. Whereas the rest of the tale — the media coverage, the scientific preparedness — is science fiction, there is really no fundamental reason why the story could not have unfolded much as I have described.

To make this possible for future impacts, we need to continue to pursue the goal of finding as many near-Earth objects (NEOs) as possible, especially those on their final approach to Earth that could arrive with little or no warning, like Chelyabinsk. I like to call these "death plunge" objects because they are already



This sequence of near-infrared images shows the first fragment of Comet Shoemaker-Levy 9 impacting Jupiter. The bright object to the right is the moon Io, while the region at lower left center is the Great Red Spot. The impact point on Jupiter's southeastern limb first flares to brightness in the second image and rivals Io at its brightest point in the third image. The fourth image, taken roughly 20 minutes after impact, shows the fireball already fading from sight. CALAR ALTO OBSERVING TEAM

The Tunguska event in 1908 ranks among the most powerful explosions in recorded history. Luckily, the meteor exploded in the air over a remote region in Siberia. LEONID KULIK EXPEDITION

falling to their demise when they are discovered. They are not going to go around their orbit again, and there is no time to deflect them. Fortunately, most will likely be much smaller than Chelyabinsk. In most cases, they will be so small that they are no threat at all, but merely an opportunity for science and tourism.

Jupiter test-bed

My idea of death plunge science was inspired by the events surrounding Comet Shoemaker-Levy 9 (SL9) in 1994, which was the first death plunge object to be discovered before impact. Luckily, it had taken aim at Jupiter, not Earth. I was fortunate to be a member of the team that used the mightiest computer on Earth at the time to make predictions about the comet's exciting final act.

Carolyn Shoemaker, one of SL9's discoverers, first described the comet March 25, 1993. "I don't know what this is," she said. "It looks like … like a squashed comet." It looked that way because it was no longer one comet, but had broken into about 20 fragments. It was in orbit around Jupiter and had passed so close that tidal stress from the planet had torn it apart.

By the time it was discovered, it was in its final two-year orbit around the planet, too late for any hypothetical jovians to attempt a deflection mission. Within months, scientists determined that the fragments would collide in July 1994, and further observations refined the trajectory and predicted specific impact locations and times. With no cities or lives at stake, researchers could focus on scientific observations.

IN DEFENSE OF EARTH by Rusty Schweickart

Asteroids are multidimensional space attractions with facets that appeal to scientists, explorers, entrepreneurs, and the wider public. And among all these groups, much of the discussion of late comes from the crowd (of which I am a part) concerned with public safety — protection from asteroid impacts, or planetary defense.

Most of our focus has been on the long-term potential for impact prediction and deflection. This challenging but achievable capability depends on using powerful telescopes to find asteroids in space, calculate their future locations, and change their arrival time slightly if they are on a path that would intersect with Earth. We can literally prevent future impacts.

But more recently we discovered that even a set of small telescopes, like the Asteroid Terrestrial-impact Last Alert System (ATLAS), can see asteroids when they're very close and about to hit. This first happened in October 2008 when a Catalina Sky Survey telescope picked up a small asteroid in the evening sky that actually hit Earth 19 hours later! Discovering it even that close to impact allowed NASA's Near-Earth Object (NEO) Program to analyze its trajectory and predict precisely when and where it would hit.

It quickly became evident that a short-term (or last minute) warning system for asteroid impacts was possible. Planetary defense suddenly had two strategies: long-term prediction and prevention, and short-term civil defense. "Duck and cover" re-entered the lexicon — or, with just a few hours' of warning, evacuation.

Interestingly, this short-term strategy to avoid impact threats to life (albeit not to property) suddenly put NEO programs on the radars not only of the civil defense systems of the world, but also of the general public. Unlike the long-term impact prevention aspect of planetary defense, where the public is a largely unwitting beneficiary, here the public is an active participant in evacuation and preparation. In fact, success depends on the public responding rationally to a threat completely outside their experience.

Who warns them? How are they warned? Duck and cover or evacuate? How does the identification of a moving spot in a small telescope's field of view get out as news to real people in time to save lives? These questions and many more will be addressed as part of Asteroid Day on June 30, an event whose goal is to familiarize the public with this unfamiliar threat and how to respond (see www.asteroidday.org).

It is truly amazing that with inexpensive technology available right now, we can prevent almost all of the potential loss of life from asteroid impacts, both long- and short-term. We are not dinosaurs, nor part of the 70 percent of life that was wiped out with them 66 million years ago. We have the tools and can act instead of merely observe. We can do this.

Rusty Schweickart *is a former Apollo 9 lunar module pilot and founded the Association of Space Explorers and the B612 Foundation, which focuses on planetary defense.* NASA (EARTH IMAGE)

The timing of the discovery was perfect because a convergence of developments in 1994 enabled planetary scientists to take full advantage. The Hubble Space Telescope had just been serviced and was now operating as originally designed, producing exceptionally high-quality images. Sandia Labs in New Mexico had recently installed the most powerful computer in the world and had just developed a parallel version of a nuclear weapons-related code that enabled us to model the impact event at high enough resolution to make useful predictions. In science, prediction is everything, especially when there is disagreement — which there was.

Two members of our modeling team were experimentalists by training, and we began to think of the impact of SL9 as a giant experiment in the sky that would either provide validation for our computer models or show us where we had gone wrong. This was an experiment larger than any you could ever carry out in a lab on Earth — or want to.

Considering the lack of human design for this experiment, it was brilliantly formulated. For one thing, a good researcher does a series of experiments with a range of parameters, and that's what we had with about 20 fragments of various sizes. The event also contained elements that even the cleverest experimentalist might not have thought to include. At the time of the orbital calculations, everyone was disappointed that the impact sites would be on Jupiter's far side. But it was not a total loss. The fragments would hit just over the southeastern limb. Jupiter's phase would be slightly less than full at the time of impact, with a dark strip between the eastern limb and the dawn terminator. The comet fragments would pass into the shadow of Jupiter before going below the limb, and any debris or ejecta coming back up would rise over the limb into darkness before being illuminated by the Sun. These would potentially be discrete events.

As it turned out, our simulations showed that sufficiently large fragments would produce fireballs, or plumes of incandescent hot gas, that would rise above the limb and be bright enough to be seen from Earth. As they kept rising, they would emerge into sunlight, at which point they would scatter light from condensed particles. We advised the Hubble Imaging Team to set up an observational sequence for Jupiter's limb. The imaging program included the first fragment as well as a few of the brighter (and presumably larger) pieces. The Hubble images beautifully confirmed our model predictions for plume-forming impacts on Jupiter. But what about Earth?

The Catalina Sky Survey is the result of a 1998 congressional directive to find and characterize at least 90 percent of the near-Earth objects 0.6 mile (1 kilometer) or larger. NASA declared this goal achieved, but the hunt is still on for medium-sized asteroids. CATALINA SKY SURVEY, UNIVERSITY OF ARIZONA

Searching closer to home

We quickly realized that the properties of Jupiter's atmosphere that led to the formation of the giant plumes were not unique to that planet. The same physics should control the aftermath of an airburst on Earth. We began to run similar models for Earth impacts and showed that high plumes form as the result of impacts the size of the one that exploded over Siberia in 1908: the Tunguska event.

Our model seemed consistent with the sketchy historical observations, but we didn't have a "validation experiment" this time. We were now doing historical science, which is subject to interpretation, difficult to quantify, and easy to dismiss. That's not very satisfying for a physicist. When we wrote up our work in a 1997 paper, we pointed out that sources of data for airbursts on Earth included U.S. government sensors, infrasound detectors, and seismic data, all operating in what is essentially "open shutter" mode. If something happened in a fortuitous location, it would be recorded, but no observational campaign existed.

We suggested a methodical search for asteroids of the size that generate the airbursts we theorized and proposed a ground-based survey system capable of providing short advance notice of a 100-kiloton-range impact, so that we could characterize an approaching object before it struck. We explained that this would enable validation of our predictions, as well as provide immensely better data on impact events.

Technology has advanced greatly in the past two decades, and while current surveys such as NEOWISE, Pan-STARRS, and the Catalina Sky Survey are making steady progress in cataloging devastation-range near-Earth objects, there is no reason that the threshold for discovery cannot be lowered to a few kilotons — events that happen several times every year. Most events would not be as spectacular or conveniently located as Chelyabinsk, but the creation of a comprehensive death plunge observational campaign would provide rapid benefits to both science and planetary defense. It also would supply a constant flow of meteorites from objects that had been observed in space, at a fraction of the cost of an asteroid sample return mission.

Economic benefits also raise the appeal of such a campaign. Excited tourists might be willing to spend a significant amount of money to see a rare cosmic spectacle and help collect meteorites on the ground. Perhaps the allure of adventure and the increasingly high value of meteorites would be incentive enough for deep-pocketed investors to help scientists, humanity, and themselves — all at the same time.

Technologically, there is no better time than now to create an international partnership among governments and private financiers to pay for infrared space telescopes and ground-based observatories to search for incoming asteroids. If that happens, it will just be a matter of time before tickets go on sale for the next death plunge event!

EXPLORE MORE DETAILS ABOUT CHELYABINSK'S 2013 DEATH PLUNGE METEOR AT **www.Astronomy.com/toc.**

Get set for Asteroid Day

On June 30, 2015, the 107th anniversary of the Tunguska event, Asteroid Day will mark a milestone in worldwide awareness of the dangers of near-Earth asteroids.

by David J. Eicher

Queen guitarist and astrophysicist Brian May speaks alongside fellow Asteroid Day founders Lord Martin Rees (left) and Grigorij Richters (center). ASTEROID DAY

Apollo 9 astronaut Rusty Schweickart announces the launch of Asteroid Day at an event in California. ASTEROID DAY

Mark Boslough of Sandia National Laboratories in New Mexico used supercomputers to simulate the fireball from an asteroid exploding in Earth's atmosphere. See his story on "death plunge asteroids" on p. 28. RANDY MONTOYA/SANDIA NATIONAL LABORATORIES

It commenced with a press conference, streamed onto the Internet, featuring a rock star, a filmmaker, and a cosmologist. On December 3, 2014, at the Science Museum in London, Brian May, astrophysicist and Queen founder and guitarist; Grigorij Richters, producer and director of the film *51 Degrees North*; and Lord Martin Rees, Astronomer Royal for England, made an announcement.

They asked for global participation in "Asteroid Day," an event to be held June 30, 2015, the 107th anniversary of the Tunguska event, an explosion caused by an incoming asteroid or comet that flattened more than 800 square miles (2,000 square kilometers) of forest along the Podkamennaya Tunguska River in central Siberia. Asteroid Day is thus intended to raise awareness about the threat from Earth-crossing asteroids. The trio read a declaration about the danger our planet faces from impacts by small solar system bodies, a document signed by 100 important scientists, astronaut-explorers, entrepreneurs, and celebrities. They described activities that will take place this June, and they started a movement to raise awareness of the danger from small bodies in the solar system.

Mainstream planetary scientists have climbed on board the Asteroid Day bandwagon. "Near-Earth objects are the leftover bits and pieces from the early solar system formation process, and they are among the least changed members of that system," says Don Yeomans, recently retired after a distinguished career at NASA's Jet Propulsion Laboratory.

David J. Eicher *is editor of* Astronomy, *a signatory of the 100x Asteroid Day Declaration, and Asteroid Day's editor-in-chief.*

An airburst over Siberia in 1908 leveled trees over an area four times the size of Lake Tahoe and created a shock wave that threw residents in the air dozens of miles away. LEONID KULIK EXPEDITION

The impact that created Meteor Crater in Arizona would have sent 900 mph (1,450 km/h) winds blasting out across a 4-mile (6km) radius, instantly killing any creatures in the area. METEOR CRATER

Although such objects may have contributed organic materials that could have established life on Earth, Yeomans reminds us they also could extinguish life. “If we don’t find them before they find us, we may not even have a future,” he says.

Rusty Schweickart, Apollo 9 astronaut and champion of the concept of planetary defense, feels passionately about the event. “Asteroid Day is a wonderful opportunity for those of us who have been working on preventing asteroid impacts with Earth,” he says. “June 30 is a special day on our calendar because it marks the day when, just over 100 years ago, an asteroid impact devastated 800 square miles of Russian forest. Happily, there was no city there as it would have been similarly devastated.”

“But asteroid impacts lie outside the intuitive experience of everyone on the planet,” says Schweickart. “So to help out with introducing asteroid impacts and planetary defense to the public, we’ve formed an expert panel to see that only the latest, best information gets passed on via Asteroid Day. This is a fun and fascinating subject and ultimately critical to the long-term survival of life here on Earth.”

The panel consists of Schweickart, Yeomans, Mark Boslough of Sandia National Laboratories, Peter Brown of the University of Western Ontario, astronaut and planetary scientist Tom Jones, and planetary defense specialist Debbie Lewis.

The founding partners in the Asteroid Day movement are many, including the Association of Space Explorers, *Astronomy* magazine, the California Academy of Sciences, Films United, the Museum of Flight, the Museum of Natural History in Vienna, the Planetary Society, the Sentinel Mission, and the Starmus Festival.

ASTEROID FREQUENCY

Asteroid size	Result	TNT explosion equivalent	Frequency
16 feet (5m)	Bright fireball	10 kilotons	3 years
82 feet (25m)	Airburst event	1 megaton	200 years
164 feet (50m)	Local devastation	10 megatons	2,000 years
460 feet (140m)	Regional devastation	300 megatons	20,000 years
985 feet (300m)	Continental devastation	2,000 megatons	70,000 years
1,970 feet (600m)	Widespread devastation	20,000 megatons	200,000 years
0.6 mile (1km)	Global catastrophe	100,000 megatons	700,000 years
3 miles (5km)	Global catastrophe	10 million megatons	30 million years
6 miles (10km)	Mass extinction	100 million megatons	100 million years

Source: Asteroid Day expert panel

A live stream of Asteroid Day activities will be aired online June 30. The organizers expect to have a variety of science-related content in the program on that day. Please check the website, www.asteroidday.org, as the day approaches. Recently, I wrote an expansive story about the realities of near-Earth asteroid impact dangers. It is an online exclusive, and you can read the entire story at www.Astronomy.com/asteroids.

The risks from near-Earth asteroids are real. And the effects of an asteroid impact on Earth vary wildly with the size of the impactor, so the data about what’s out there, which is still partially unknown, become critical. Understanding the risks from asteroid impacts on Earth is a pretty young exercise, as is the case with much of astronomy and planetary science. We now know that future dangerous impacts will happen, though they may be many years away.

From a planetary scientist’s view, however, it would be grossly negligent to avoid completing as thorough a survey as possible of all the space rocks in Earth-crossing orbits and understanding other small bodies farther out in the solar system that could come our way.

It is an insurance policy for planet Earth. We should not be alarmed as concerned human beings. But we should be determined, informed, and on the clock, keeping track of solar system bodies and their movements. One day these debris will interact again in a big way with our planet. Perhaps we will discover incoming asteroids and be able to divert their course before disaster strikes. We surely will want to be ready when that day comes. Anything less would be a reckless misuse of the knowledge our species has worked so hard to gain.

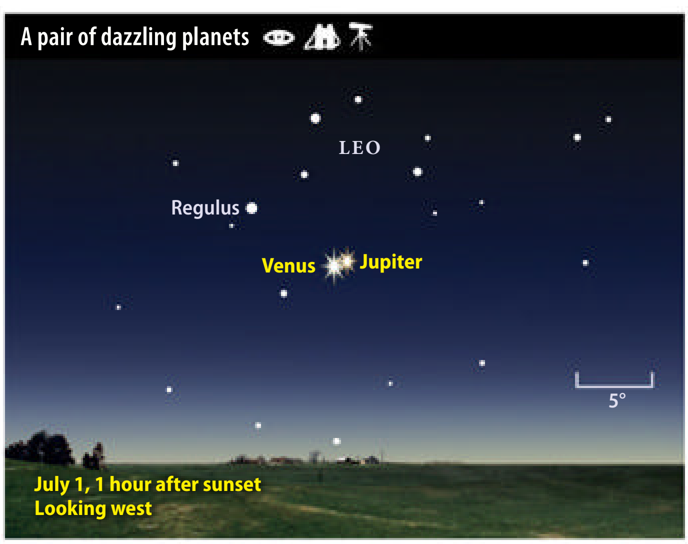
LEARN MORE ABOUT THE DANGERS OF ASTEROID IMPACTS AT **www.Astronomy.com/toc.**

MARTIN RATCLIFFE and **ALISTER LING** describe the solar system's changing landscape as it appears in Earth's sky.

Visible to the naked eye
Visible with binoculars
Visible with a telescope

July 2015: Venus dazzles at dusk

Brilliant Venus passed to the upper right of Jupiter after sunset March 12, 2012. The two planets repeat their close encounter in early July. ALAN DYER



Venus and Jupiter lie within 1° of each other July 1. Coincidentally, both then appear 32" across through a telescope. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

Pluto stands front and center during July. Not only is the New Horizons spacecraft swooping within a few thousand miles of the dwarf planet's surface — bringing humanity its first close-up views — but the distant world also reaches its annual peak in Earth's night sky. Observers with 8-inch or larger telescopes should be able to track it down.

But the solar system offers plenty of brighter fare as well. Venus and Jupiter continue to dominate the early evening sky while Saturn climbs highest in the south before midnight. During the morning hours, Uranus and Neptune become tempting targets through binoculars. And finally, it's worth taking a few minutes to view Mercury before sunrise in early July.

Anyone with a clear sky the evening of July 1 can't help but notice **Venus** and **Jupiter**. The dazzling planets stand side by side in the west with just a Full Moon's width between them. Venus shines at magnitude –4.6 and Jupiter at magnitude –1.8. Only the Full Moon itself — climbing higher in the southeastern sky this evening — appears brighter. (By the way, July brings the first "Blue Moon" — two Full Moons in a calendar month — since August 2012. July's second Full Moon occurs on the 31st.)

As twilight descends, the two planets seem to grow more brilliant in contrast with the darker sky. They hover 8° to the lower right of 1st-magnitude Regulus, Leo the Lion's brightest star, which forms the base of Leo's Sickle asterism.

The planet pair remains visible for about two hours after the Sun sets in early July. During the next few weeks, Venus moves southwest (left as seen from mid-northern latitudes) of its companion. By the 9th, 4° separate the two. Venus then shines at magnitude –4.7, the peak brightness for its current evening reign.

The two planets and Regulus create an ever-changing triangle during July. On the 18th, a slender crescent Moon joins the scene to create a perfect picture opportunity. All four objects lie within a 6° circle, with our satellite less than 1° from Venus. And on the 23rd, both Venus and Jupiter appear 4° from Regulus. The trio sinks into bright twilight by the end of July, setting within an hour of the Sun.

A telescope reveals electrifying changes in Venus' appearance this month. As the inner planet prepares to pass between the Sun and Earth in August, it draws closer to our world while turning its illuminated hemisphere away from us. Its apparent diameter grows by some 60 percent — from 33" to 52" — while its phase dwindles from 33 percent to 7 percent lit.

Details in Jupiter's atmosphere become harder to see in July as the planet sinks closer to the horizon. A lower altitude means its light passes

Martin Ratcliffe *provides planetarium development for Sky-Skan, Inc., from his home in Wichita, Kansas. Meteorologist* **Alister Ling** *works for Environment Canada in Edmonton, Alberta.*

RISING**MOON**

No glory for Galileo

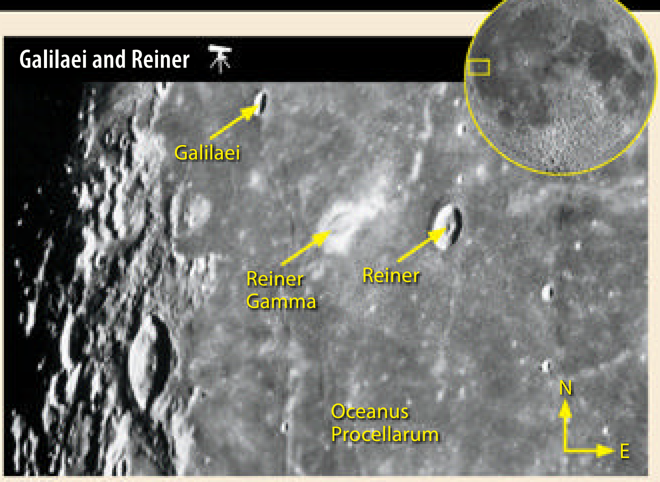
The Moon is a world unto itself, but humans have dressed its face with an honor roll of great scientists and philosophers in Earth's history. Generally speaking, the bigger the name, the more impressive the feature, with the most striking reserved for those luminaries of the pre-telescope age.

But the great Italian scientist Galileo Galilei must have rubbed lunar cartographers the wrong way because "his" crater (Galilaei) is only half the size and much less prominent than the one named for his friend and student, Vincentio Reinieri (Reiner). Appropriately, the two craters appear near each other in the large western "sea" named Oceanus Procellarum. Look for them due west of Copernicus, the dominant large crater with the prominent rays just north of the lunar equator.

Galilaei spans 10 miles and shows a sharp rim. It formed well after the heavy bombardment and huge lava floods that characterized the earlier parts of the Moon's history. Reiner lies to its neighbor's southeast and appears equally fresh.

As evening arrives in North America on July 28, the waxing gibbous Moon stands high in the south. The lunar terminator — the line dividing day from night on the Moon — then cuts right through Galilaei about 10° north of the lunar equator. If light from the bright disk bothers your eyes, use a dark filter to reduce the glare or pump up the magnification to spread out the light and reduce its intensity.

The best overview of the region comes the following evening (July 29) when the scene closely matches the photo above. The Sun then lies higher in the lunar sky, so especially reflective features can catch the eye. Look for a curious white feature, Reiner Gamma, between Galilaei and Reiner. Observations during the Apollo missions confirmed that this is not a topographic feature but, similar to other white splotches on the farside, is highly magnetic. Lunar scientists have yet to reach a consensus as to what Reiner Gamma is or how it formed.



The lava fields of Oceanus Procellarum make a nice backdrop for impact craters Galilaei and Reiner. CONSOLIDATED LUNAR ATLAS/UA/LPL; INSET: NASA/GSFC/ASU

through more of Earth's turbulent air, reducing an image's sharpness. The best views will come in late twilight, roughly 45 minutes after sunset, in the first half of the month.

Tracking Jupiter's four bright moons proves much easier. All orbit in the same plane, which currently tilts edge-on to both the Sun and Earth. This means the moons themselves can occult or eclipse one another. Although these so-called mutual events have been occurring since August 2014, the observing window is closing quickly. The last one comes in August, but by then Jupiter will be hopelessly lost in the Sun's glare. This means early July is your last chance to witness one of these intriguing events until the satellite orbits align again in six years.

Perhaps the best such event for North American observers

— Continued on page 42

METEORWATCH

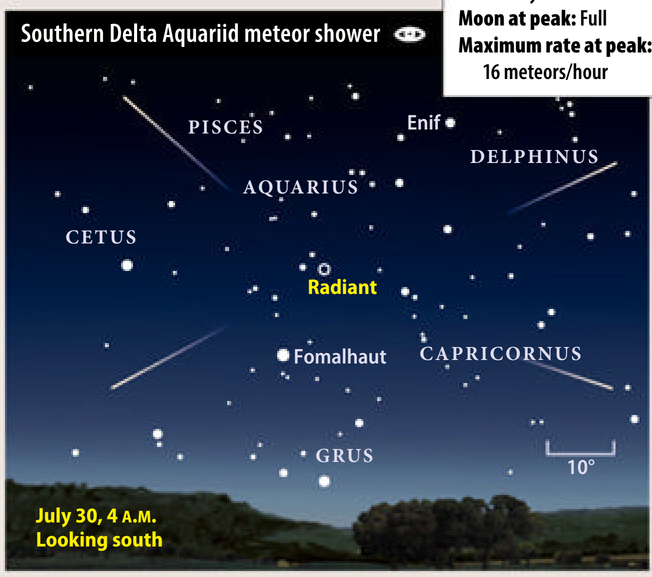
There's a bad Moon on the rise

July features several meteor showers, though none rises to major status. The Piscis Austrinids and Alpha Capricornids each deliver a maximum of five meteors per hour at their late July peaks, though Southern Hemisphere observers have better views.

The month's best performer is the Southern Delta Aquariid shower, which typically produces 15 to 20 meteors per hour. Unfortunately, it peaks the morning of July 30, just one day before the month's second Full Moon. The shower does maintain its peak level for several days, however, so you'll likely get a better show if you watch in the hour or two between moonset and the start of morning twilight July 27 and 28.

Southern Delta Aquariid meteors

Active Dates: July 12–Aug. 23
Peak: July 30
Moon at peak: Full
Maximum rate at peak: 16 meteors/hour



Although a Full Moon interferes with July's top meteor shower, observers should spy some "shooting stars" on the month's final mornings.

OBSERVING HIGHLIGHT Pluto reaches opposition and peak visibility July 6, when it glows at magnitude 14.1 among the background stars of northern Sagittarius.

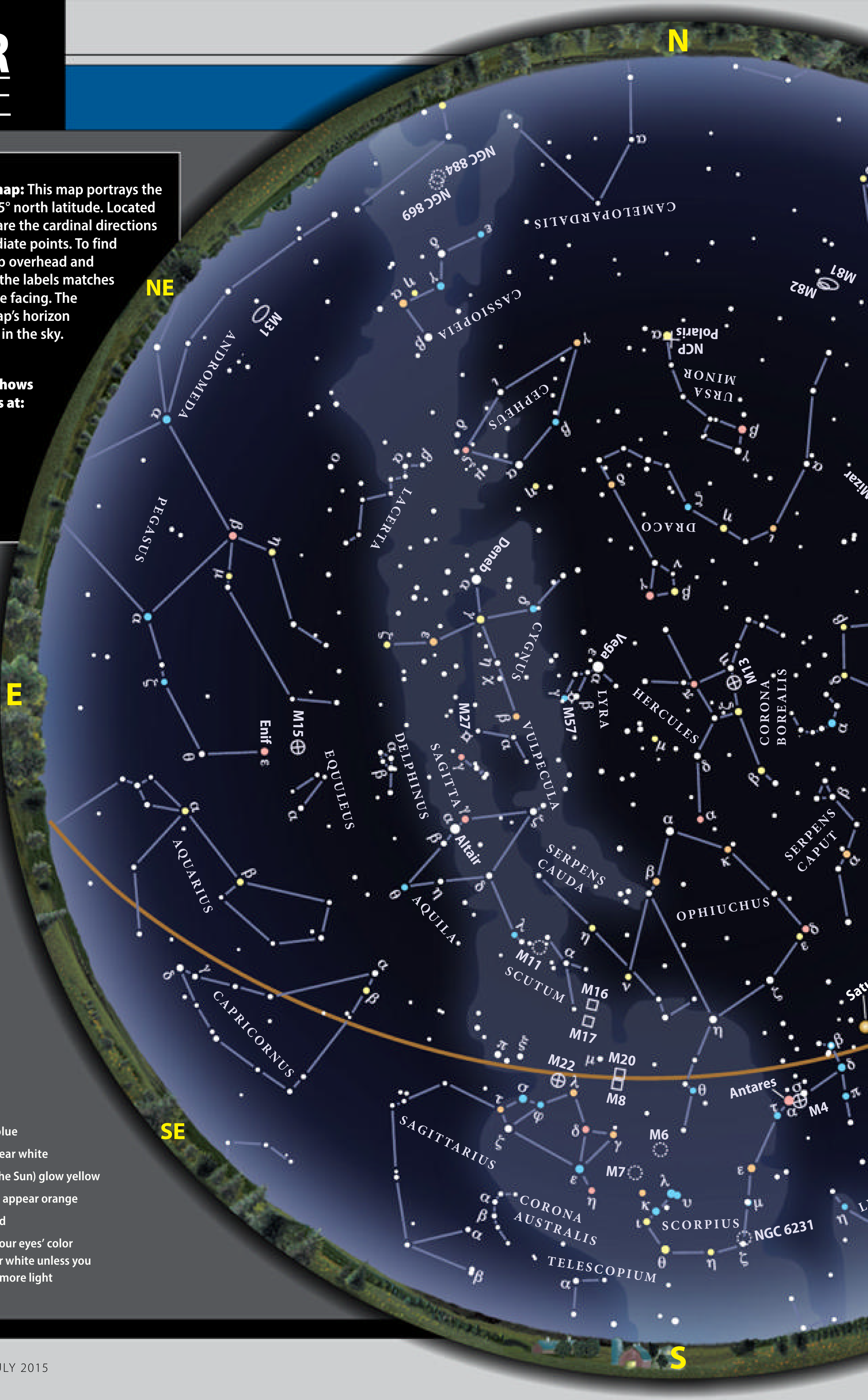
STAR DOME

How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

midnight July 1
11 P.M. July 15
10 P.M. July 31

Planets are shown at midmonth



STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

JULY 2015

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

Calendar of events

1 Venus passes 0.4° south of Jupiter, 10 A.M. EDT

Full Moon occurs at 10:20 P.M. EDT

5 The Moon is at perigee (228,101 miles from Earth), 2:52 P.M. EDT

6 The Moon passes 3° north of Neptune, 4 A.M. EDT

Pluto is at opposition, noon EDT

Earth is at aphelion (94.5 million miles from the Sun), 4 P.M. EDT

8 Last Quarter Moon occurs at 4:24 P.M. EDT

The Moon passes 0.8° south of Uranus, 11 P.M. EDT

SPECIAL OBSERVING DATE

9 Venus gleams at magnitude –4.7 today, the brightest it gets during this evening apparition.

12 The Moon passes 0.9° north of Aldebaran, 2 P.M. EDT

15 New Moon occurs at 9:24 P.M. EDT

18 The Moon passes 4° south of Jupiter, 2 P.M. EDT

The Moon passes 0.4° south of Venus, 9 P.M. EDT

21 The Moon is at apogee (251,553 miles from Earth), 7:02 A.M. EDT

23 Venus is stationary, 2 A.M. EDT

Mercury is in superior conjunction, 3 P.M. EDT

24 First Quarter Moon occurs at 12:04 A.M. EDT

25 Asteroid Ceres is at opposition, 4 A.M. EDT

26 The Moon passes 2° north of Saturn, 4 A.M. EDT

Uranus is stationary, noon EDT

30 Southern Delta Aquariid meteor shower peaks

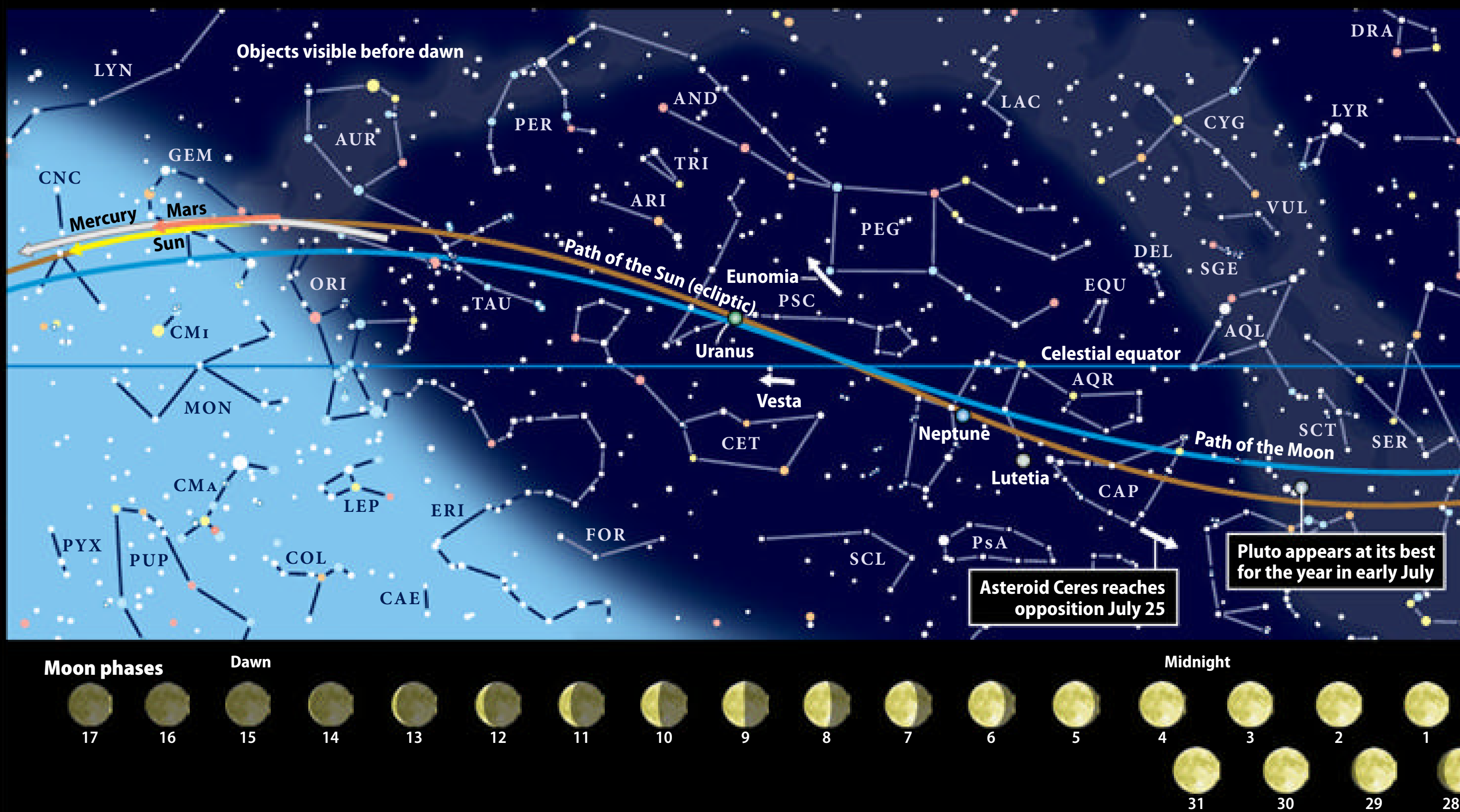
31 Full Moon occurs at 6:43 A.M. EDT

Venus passes 6° south of Jupiter, 4 P.M. EDT

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

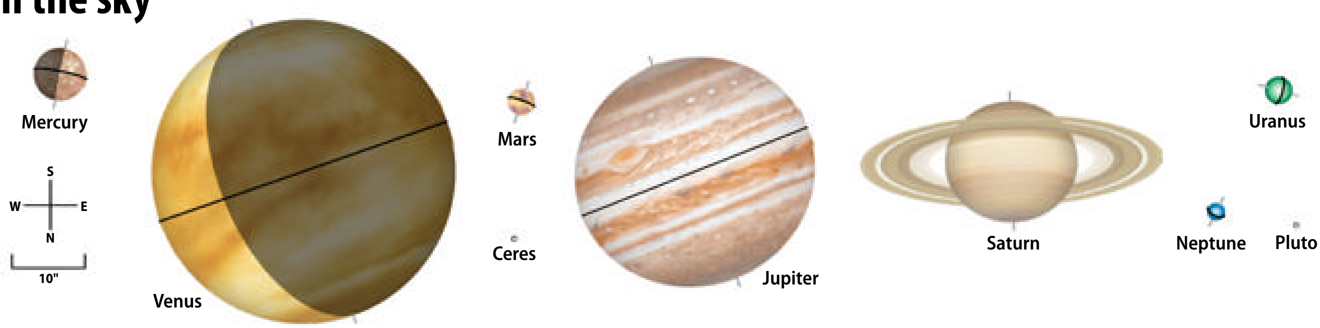
PATH OF THE PLANETS

The planets in July 2015



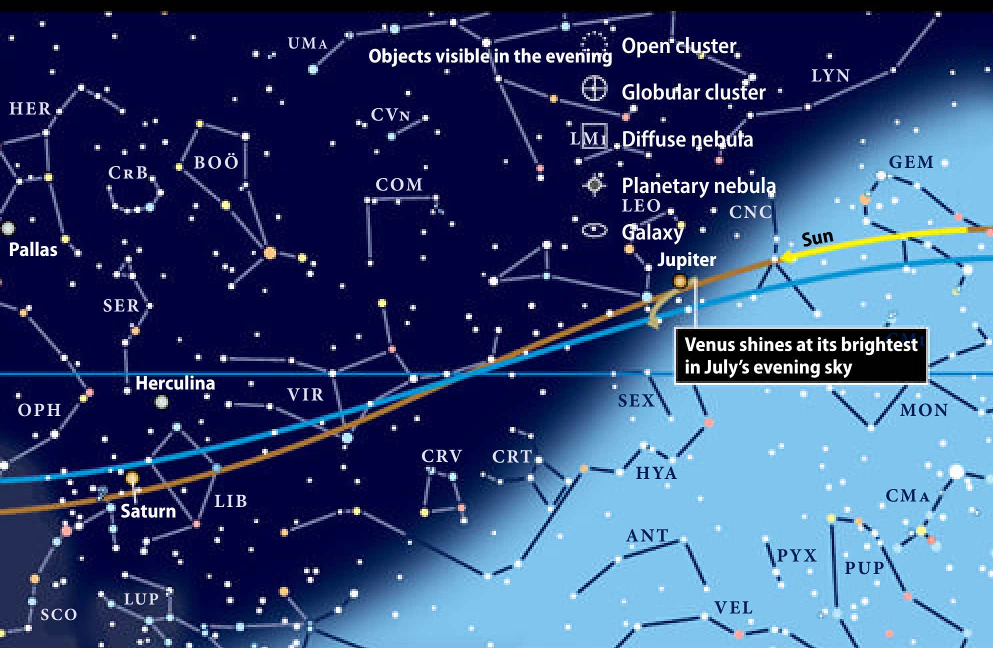
The planets in the sky

These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets for the dates in the data table at bottom. South is at the top to match the view through a telescope.



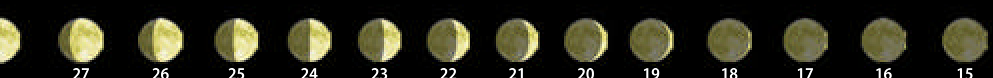
Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	July 1	July 15	July 15	July 15	July 15	July 15	July 15	July 15	July 15
Magnitude	–0.2	–4.7	1.6	7.6	–1.8	0.3	5.8	7.8	14.1
Angular size	7.0"	40.2"	3.6"	0.7"	31.7"	17.8"	3.5"	2.3"	0.1"
Illumination	52%	22%	100%	100%	100%	100%	100%	100%	100%
Distance (AU) from Earth	0.963	0.415	2.587	1.949	6.212	9.351	19.933	29.265	31.903
Distance (AU) from Sun	0.368	0.727	1.589	2.940	5.377	9.987	19.990	29.964	32.909
Right ascension (2000.0)	5h06.9m	10h00.8m	6h58.8m	20h36.8m	9h46.6m	15h46.2m	1h15.7m	22h44.8m	18h59.2m
Declination (2000.0)	20°35'	10°27'	23°36'	–29°12'	14°19'	–17°47'	7°18'	–8°49'	–20°46'

This map unfolds the entire night sky from sunset (at right) until sunrise (at left).
Arrows and colored dots show motions and locations of solar system objects during the month.



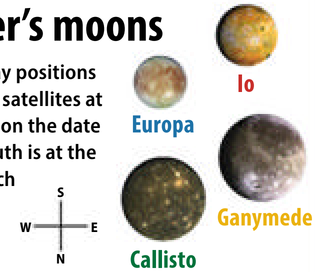
Early evening

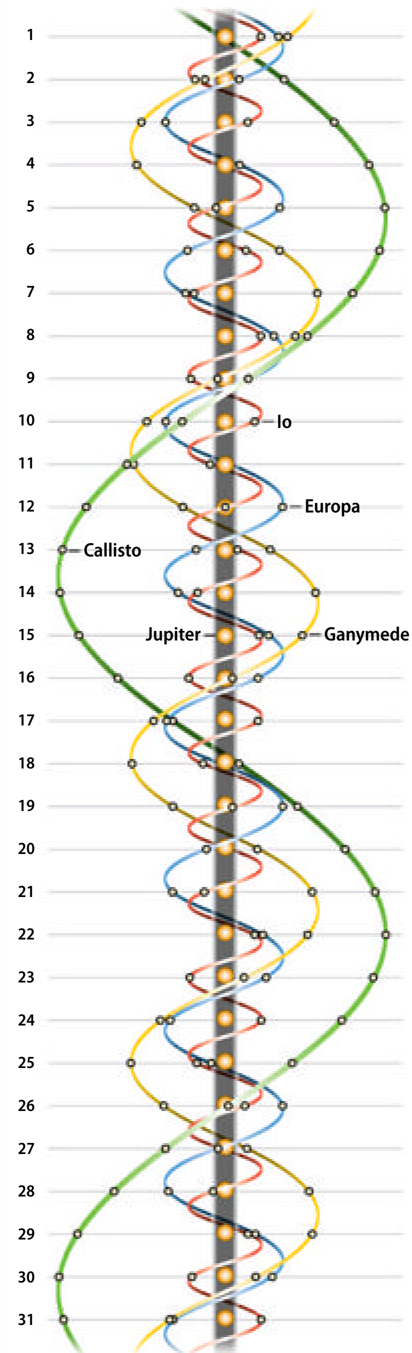
To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.
Note: Moons vary in size due to the distance from Earth and are shown at 0h Universal Time.

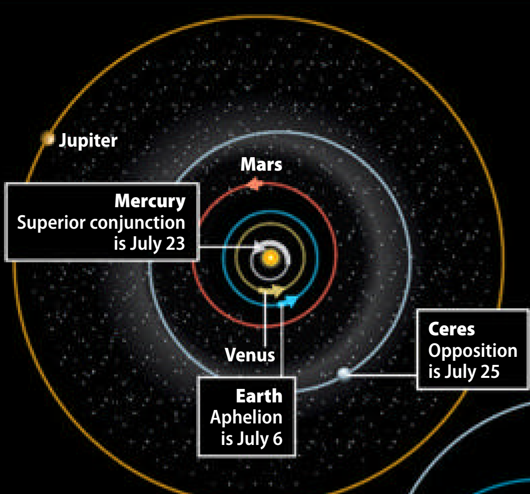


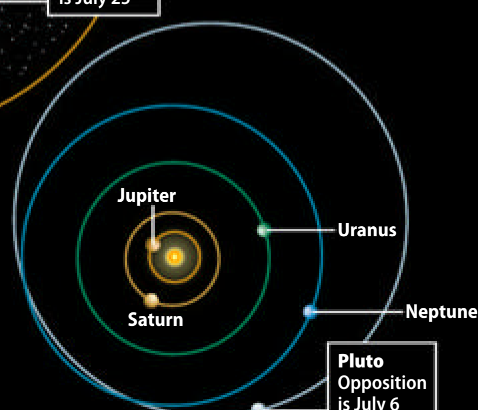
Jupiter's moons

Dots display positions of Galilean satellites at 11 P.M. EDT on the date shown. South is at the top to match the view through a telescope.









The planets in their orbits

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at mid-month from high above their orbits.

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

— *Continued from page 37*

WHEN TO VIEW THE PLANETS

EVENING SKY	MIDNIGHT	MORNING SKY
Venus (west)	Saturn (southwest)	Mercury (northeast)
Jupiter (west)	Neptune (southeast)	Uranus (southeast)
Saturn (south)		Neptune (south)

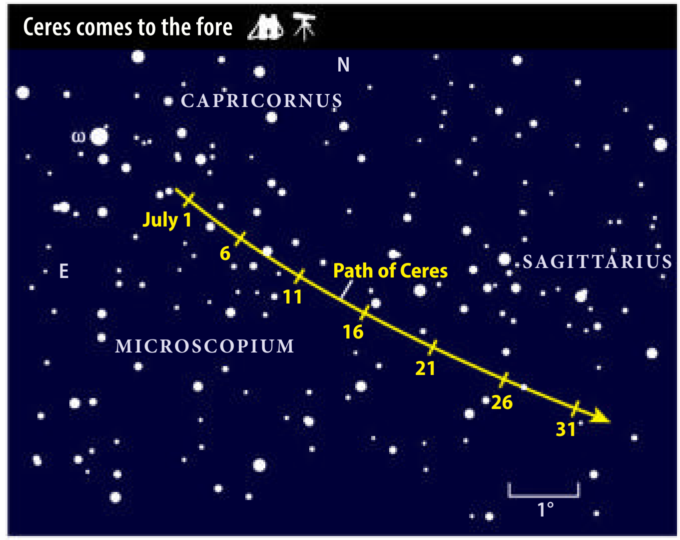
happens the evening of July 2. Starting at 10:29 P.M. CDT, Ganymede partially occults Io for four minutes. (Because of Jupiter's limited visibility, only viewers in the Central and Mountain time zones can witness this event.)

Io returns the favor July 5 when it occults giant Ganymede for observers in western North America. The event begins at 10:18 P.M. MDT and lasts just two minutes. Two days later, on July 7, the same region sees Io occult Europa for five minutes commencing at 9:46 P.M. MDT.

Saturn stands roughly 30° above the southern horizon as darkness falls in July. The ringed planet shines at magnitude 0.3 at midmonth and is the brightest object in this part of the sky. It glows twice as bright as 1st-magnitude Antares, the luminary of the constellation Scorpius, which lies 13° southeast of the planet.

Despite its proximity to Scorpius, Saturn actually lies among the background stars of eastern Libra the Balance. A waxing gibbous Moon passes 2° north of the planet the night of July 25/26.

A telescope delivers spectacular views of Saturn and its rings. The planet's disk appears 18" across in mid-July while the ring system spans 40" and tilts 24° to our line of sight. Any instrument should reveal the Cassini Division, a slim black gap that separates the outer A ring from the brighter B ring. Look carefully and you also might glimpse the gossamer-thin C ring close to the planet.



Dwarf planet Ceres reaches opposition and peak visibility in late July near the nexus of constellations Sagittarius, Capricornus, and Microscopium.

Saturn also rules over a family of modestly bright moons. Any telescope reveals 8th-magnitude Titan, the planet's largest satellite. It passes due north of Saturn on July 6 and 22 and due south on the 13th and 29th. A 4-inch scope also reveals 10th-magnitude Tethys, Dione, and Rhea, which all orbit closer to Saturn than does Titan.

Each night these four moons change positions relative to one another and to Saturn. On July 5, look for Tethys and Dione just 7" apart northwest of the planet, with Titan 1' north of the pair and Rhea 44" west of Tethys. On the 11th, Tethys, Dione, and Rhea form a straight line extending northeast from Saturn, with Titan well to their southeast.

The outermost bright moon is Iapetus, which takes 79 days to revolve around

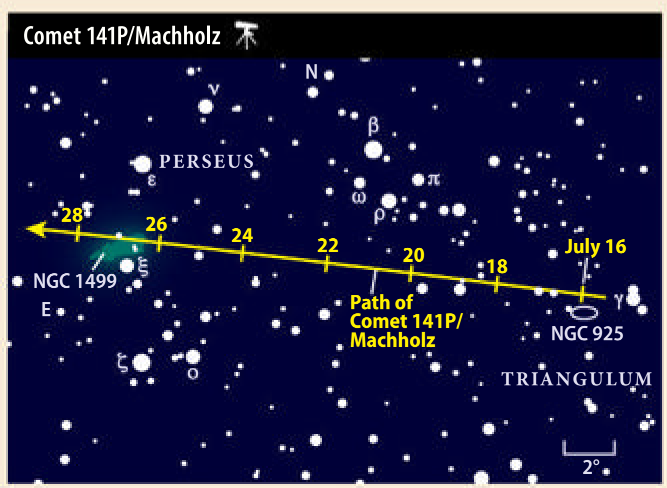
COMETSEARCH

A comet with a split personality

The comet drought of the past few months is coming to an end. Although none of July's icy visitors reach naked-eye visibility, telescope owners could get some nice views. Observers on each side of the equator have something to follow this month. To the south, Comet Catalina (C/2013 US10) should glow around 8th magnitude as it flies with the birds in Phoenix, Grus, and Tucana. Astronomers hope this comet will be a nice binocular object — and perhaps become visible to the naked eye — for northern observers in December and January.

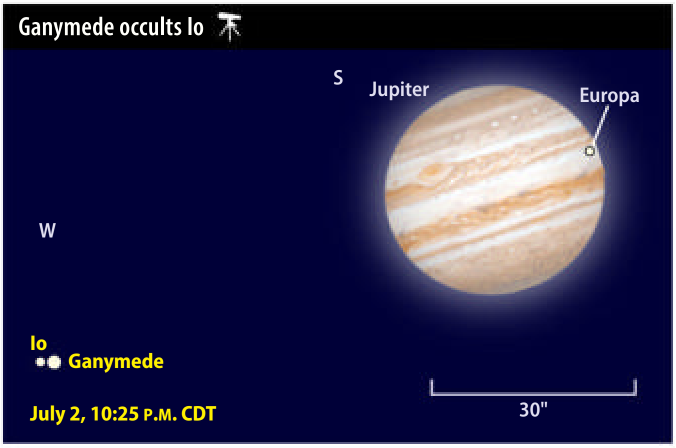
In the Northern Hemisphere, the fainter but fascinating Comet 141P/Machholz beckons. Ever since Don Machholz discovered it in 1994, this loosely packed ice ball has been breaking up and flaring. Of the five original components, only two came back in 2000 and just one was seen in 2005. The comet hid behind the Sun at its 2010 return, so no one observed it. Will there be anything left this time, or will we witness a spectacular final breakup?

During July, Machholz covers a large strip of sky from Pisces to Perseus. Visual observers should wait until New Moon on July 15/16 and use an 8-inch or larger instrument to hunt for the comet before dawn. It then



If this periodic comet remains intact, it could deliver nice views when it passes galaxy NGC 925 and the California Nebula (NGC 1499).

lies near 4th-magnitude Gamma (γ) Trianguli and 10th-magnitude spiral galaxy NGC 925. An even closer celestial encounter occurs July 26 and 27 when the comet slides through the northern part of the California Nebula (NGC 1499).



Only a few more mutual events occur among Jupiter's moons this decade. Ganymede passes in front of Io on July 2, a few minutes after this scene.

Saturn. It passes 2.2' south of the planet July 16 and spends the rest of the month heading toward a greatest western elongation in early August. Whenever Iapetus lies well west of the ringed world, its brighter hemisphere faces Earth and it glows at 10th magnitude. When the moon is far east of the planet, as it is in early July, it appears just one-fifth as bright. You should be able to track Iapetus' growing brightness if you follow it all month.

People will long remember July 2015 as the month when humans got their first close-up look at **Pluto**. The New Horizons spacecraft flies past the distant world July 14 and should be returning extraordinary views to eager scientists all month. By a stroke of luck, Pluto also reaches opposition and peak visibility this month. Observers with 8-inch or larger telescopes can track down the 14th-magnitude point of light. For viewing tips and detailed finder charts, see "Hunt the last planet" on p. 46.

When the International Astronomical Union reclassified Pluto as a "dwarf planet" in 2006, they also added the largest asteroid, **Ceres**, to this new group. Remarkably, both objects reach opposition this month while under the intense scrutiny of a visiting spacecraft (NASA's Dawn probe in the case of Ceres). The asteroid is far easier to spot, however, because it glows at magnitude 7.5 at its July 25 opposition. Use binoculars or a telescope and the finder chart on p. 42 to track it down on the border between Sagittarius and Microscopium.

Neptune rises shortly before midnight local daylight time and climbs highest in the south as twilight begins. You can find the magnitude 7.8 planet through binoculars among the background stars of Aquarius the Water-bearer. Use 4th-magnitude Lambda (λ) Aquarii as your guide. Neptune begins July 2.1° southwest of the star; the gap grows to 2.6° by month's end. Through a telescope at moderate magnification, the planet shows a blue-gray disk that spans 2.3".

Although it lies just one constellation east of Neptune, **Uranus** doesn't clear the eastern horizon until around 2 A.M. local daylight time in early July. (It rises two hours earlier by month's end.) Glowing at magnitude 5.8 against the backdrop of Pisces the Fish, it is quite easy to spot through binoculars. Uranus spends the month within 0.6° of 5th-magnitude Zeta (ζ) Piscium and is the brightest object southwest of this star. A telescope reveals the planet's 3.5"-diameter disk and distinctive blue-green hue.

Mercury shines brightly in morning twilight during July's first two weeks. On the 1st, it glows at magnitude –0.2 and stands 8° high in the east-northeast a half-hour before sunrise. A telescope shows a disk 7" across and just over half-lit. The inner world mostly maintains this altitude each morning during July's first week while brightening about 0.1 magnitude each day. On the 7th, it appears 6" in diameter and the Sun illuminates 70 percent of its disk. Mercury dips deeper into the twilight and becomes harder to see in the following week. It passes behind the Sun from our viewpoint July 23.

Mars remains lost in the Sun's glare throughout July. It will return to view before dawn in late August.

LOCATING**ASTEROIDS**

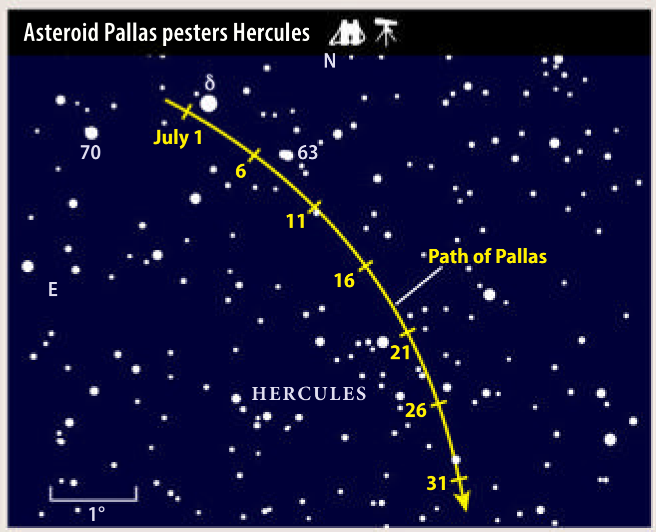
Pallas glides through the Strongman

If you can make out Hercules the Strongman in July's late evening sky, you should have little problem pegging asteroid 2 Pallas. It doesn't get much easier than on July 1 and 2, when the space rock passes within 0.3° of 3rd-magnitude Delta (δ) Herculis, the constellation's third-brightest star.

The finder chart below should help you pick out Pallas on other nights. If you can't identify the asteroid quickly, a surefire way is to watch it move from night to night. Sketch the four or five dots closest to the asteroid's marked position, and then return a night or two later. The "star" that moved is Pallas.

Many seasoned observers use this method so they can be sure they haven't spotted a background star near Pallas' brightness. (The 325-mile-wide asteroid dims from magnitude 9.5 to 9.8 this month.) On July 11, 20, and 30, Pallas passes close enough to a field star that it shifts position noticeably in just four or five hours.

Unlike the planets and most main-belt asteroids, Pallas' orbit inclines steeply to the plane of the solar system. Notice how far north it is now — placing it in prime position for Northern Hemisphere observers — by comparing its position with Saturn some 40° to the south.



Look for Pallas within 0.3° of 3rd-magnitude Delta (δ) Herculis on July 1 and 2; you'll have a tougher search among fainter stars late in the month.

TITANIC RAINDROPS

Q: HOW BIG WOULD METHANE RAINDROPS BE ON TITAN?

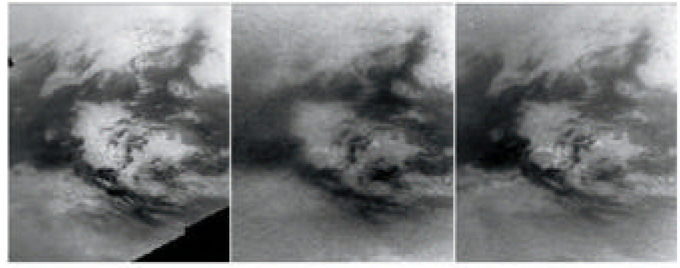
***Douglas Kaupa,** Colorado Springs, Colorado*

A: Methane raindrops on Titan could grow to be almost a centimeter across, nearly twice the size of large raindrops on Earth (about 6 millimeters). And, thanks to Titan's thicker atmosphere and lower gravity, they would fall much more slowly, roughly 5.2 feet per second (1.6 m/s), the speed at which snowflakes fall on Earth (compared to rates of terrestrial rainfall at up to 30 ft/s [9 m/s]). The slower speed and larger drops would make it easier to see that raindrops (on Titan and Earth) tend to be distorted and flattened by the atmosphere as they fall.

A consequence of falling slowly is that there is more time for raindrops to evaporate before they reach the ground, so the phenomenon of virga, seen over deserts on Earth, is likely much more common on Titan. However, we know from observations by the Cassini spacecraft that rain does occasionally reach Titan's surface. Cassini's cameras have revealed darkening of the surface in the wake of some of the largest cloud outbursts — like rain on Earth darkens the ground, except that on Titan it's methane rain wetting a surface covered in solid hydrocarbon material, and it takes weeks to months for Titan's surface to dry out again. Astronomers only have seen this a few times over more than 10 years of observations by Cassini, suggesting rainfall is rare but intense — another parallel with terrestrial deserts.

It is currently late northern spring on Titan, and based on atmospheric models similar to those used to understand weather on Earth, titanian forecasts have called for an increasing likelihood of clouds as the Sun rises higher over Titan's north polar seas. However, storms have not materialized as early as anticipated. Plans are for Cassini to continue its mission in the saturnian system until just after the northern summer solstice. So we will be watching Titan closely over the next few years to see if and when summer storms arrive. And if the timing of a storm is just right during one of Cassini's close Titan flybys, its radar instrument could even detect rain as it falls.

Elizabeth Turtle
Johns Hopkins Applied Physics Lab
Laurel, Maryland



Clouds on Titan create methane rain, causing changes on the surface below. The left image shows an area near the moon's equator May 13, 2007, while the other two were taken 15 hours apart January 15, 2011. The bright points in the latter two photos appear to be low clouds above where rain fell recently. NASA/JPL/SSI

A human's view from an Earth-like planet around a red dwarf star might look something like this artist's impression of a sunset on the exoplanet orbiting Gliese 667C, which is part of a triple star system. Astronomers suspect tens of billions of rocky worlds orbit these small stars in our galaxy. ESO/L. CALÇADA

Q: PROXIMA CENTAURI IS A RED DWARF STAR, SO WOULD IT APPEAR RED FROM THE SURFACE OF AN EARTH-LIKE PLANET IN THAT STAR'S HABITABLE ZONE?

Kevin Alcott
Naperville, Illinois

A: Astronomers haven't found planets around our Sun's nearest neighbor, the red dwarf Proxima Centauri. But there's good reason to keep looking. Most exoplanets orbit red dwarfs — the most common and longest-lived type of star. Astronomers believe as many as half might have rocky planets. And Kepler spacecraft data imply perhaps 6 percent could have Earth-sized planets in their habitable zones — the region where liquid surface water can exist. That prevalence gives hope for life in the cosmos.

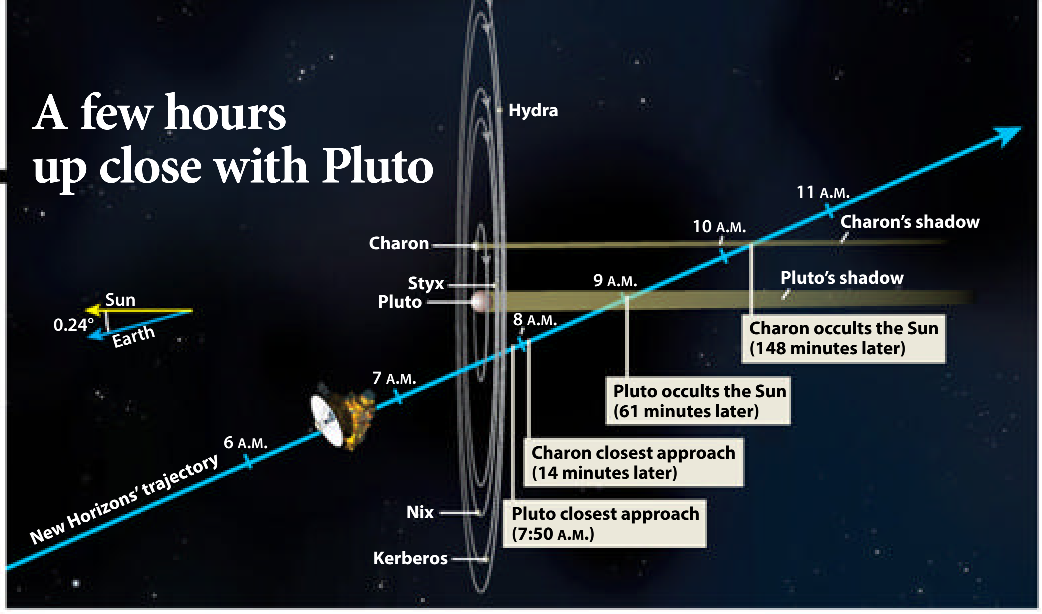
But there's also reason to doubt. Red dwarfs are much smaller than our Sun. To orbit in the habitable zone, an Earth-sized planet must huddle close to its host star. And red dwarfs can be highly active, shooting off the kind of flares that strip atmospheres. The close-in orbit could cause tidal locking, with one side in constant light and the other eternal darkness, lit only by the abundant aurorae, which would serve as harbingers of yet another solar storm. That temperature contrast between nightside and dayside also could blast hurricane-force winds across the planet — not exactly Earth-like conditions.

The recently discovered exoplanet Kepler-186f might help settle things. Astronomers think it could be the most Earth-like world found to date. The fifth planet from its red dwarf sun, this world might sit just far enough out to stay in the habitable zone while avoiding tidal lock. Light from the invisible infrared part of the spectrum would shine brightest, with a fraction of starlight falling in the red visible range. Rather than red, the light would have an orangy-yellow hue because of the way our eyes have evolved on Earth. And any aliens would be very different too. Astrobiologists predict the

red-wavelength photons would push plants relying on photosynthesis to use a wider spectrum for energy, creating red or black plants.

But could such a world exist right next door? Astronomers are currently employing the Hubble Space Telescope to watch Proxima Centauri as it passes in front of a pair of background stars. Their hope is that gravity from an orbiting planet would warp the starlight and reveal its presence. The final encounter will occur in 2016. Here's to hoping for friendly neighbors.

Eric Betz
Associate Editor



New Horizons' closest approach to Pluto just before 8 A.M. EDT on July 14 puts it some 7,770 miles (12,500 kilometers) away from that world's surface. Because the Sun is so faint in the outer solar system, a skywatcher on that world would still have a tough time noticing the flyby. *ASTRONOMY*: ROEN KELLY

Q: IF MY DOG PLUTO WERE SITTING ON THAT PLANET JULY 14, WOULD HE BE LIKELY TO CATCH A GLIMPSE OF NEW HORIZONS AS IT ZOOMS BY?

John Cawley III
Goodview, Virginia

A: The closest New Horizons will get to Pluto is about 7,770 miles (12,500 kilometers) above the surface. At this distance, the spacecraft would be only 45 arcseconds across, around the size of Jupiter as viewed from Earth. New Horizons will be traveling at 8.6 miles per second (13.8 km/s) relative to Pluto, meaning it will zip through the sky at 3 arcminutes per second. That's much slower than an International Space Station pass on Earth, but still fast enough that the spacecraft will go from horizon to horizon in a couple of hours.

The real trick is how bright the spacecraft will be. New Horizons is covered in very reflective material, but Pluto is extremely far from the Sun. At its brightest, New Horizons only will be about magnitude 18, and then for only 15 minutes at closest approach. For comparison, Pluto is about magnitude 14 now, and its largest moon, Charon, is magnitude 17.

So unless he has some serious glass, Pluto the dog will really strain to see New Horizons fly past. However, in addition to taking images and spectra of Pluto, New Horizons will probe the atmosphere of Pluto by transmitting a radio signal as it briefly passes behind the dwarf planet. Scientists back on Earth will need to use NASA's giant 70-meter Deep Space Network antennas to hear New Horizons' signal, but Pluto the dog could easily hear it with a ham radio set to the 3-centimeter band. So buy Pluto a radio set, and let him hear New Horizons call back to Earth as it flies past.

Simon Porter
Southwest Research Institute
Boulder, Colorado

Q: THE SUN HAS AN 11-YEAR SUNSPOT CYCLE. DO WE KNOW IF OTHER STARS HAVE SIMILAR LENGTHS, OR IS OUR STAR UNIQUE?

Logan Johnson
Green River, Wyoming

A: Until the 1970s, the Sun was the only star that astronomers knew exhibited magnetic cycles. Thus we had no idea whether our star's 11-year cycle (actually a 22-year magnetic cycle in the interior of the Sun) was present on other stars like it or whether there were different periods for different stars depending on their age, rotation rate, or composition.

Starting in the late 1960s, Olin C. Wilson, working from Mount Wilson Observatory above Pasadena, California, observed about 90 fairly bright stars around the sky to find out if he could detect such changes in activity and possibly even cycles. His part of the project went on for more than a decade before his retirement.

On the Sun, changes in sunspot numbers are associated with the strength of two lines of singly ionized calcium. By measuring changes in them, we can observe both the rotation and the longer-term magnetic cycles on the visible disks of stars.

Wilson took advantage of this effect to measure just the dark cores of the two calcium lines in his sample of stars to see what happened. This resulted in a seminal paper in 1978 that started the entire subject of solar-stellar activity variations. As the subject developed, the broader study of the historical variations in the Sun's brightness, including the connection between solar activity and climate, and the search for solar twins moved onto the front burner.

His research showed that other stars have activity cycles that range from a few years to indeterminately long. Some stars appear to have no change in activity and are thought to be in dormant states similar to our Sun's "Maunder minimum," a dip in solar activity that occurred in the 17th century. This variety gives us insight into our once and future Sun.

Starting in 1992, Lowell Observatory initiated a project to continue these observations of both the Sun and Wilson's original stars using our 1.1-meter telescope. Our team has maintained this work up to the present.

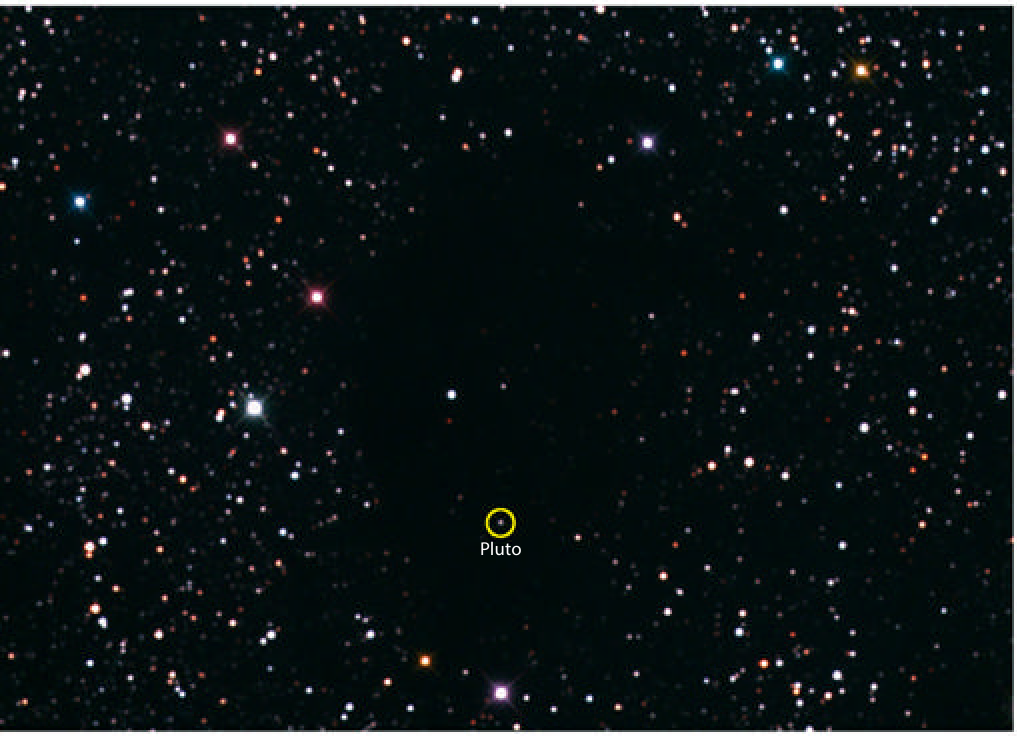
Brian Skiff
Lowell Observatory
Flagstaff, Arizona

Send us your questions

Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

Hunt the LAST PLANET

While Pluto takes center stage with New Horizons' arrival, backyard observers can get their own glimpse of this enigmatic world. **by Richard Talcott**



JOHN CHUMACK

Pluto looks like a mere dot through a telescope; the thrill comes in seeing the distant planet at all.

When astronomy enthusiasts look back on 2015, the unveiling of Pluto surely will rank among the highlights. The distant world has fired the public's imagination ever since American astronomer Clyde Tombaugh first spotted it in 1930. An intriguing and enigmatic object for most of the 85 years since, planetary scientists will get their first detailed views this July when the New Horizons spacecraft flies past. (See Principal Investigator S. Alan Stern's look at the science behind the mission on p. 22.)

Coincidentally, Pluto also comes to peak visibility in Earth's sky during July. Although the dwarf planet shines feebly at magnitude 14.1, observers under a dark sky with the right equipment who know exactly where to look can glimpse the dim glow with their own eyes. Pluto reaches opposition July 6, when it lies opposite the Sun in our sky and stays visible all night. But the planet's visibility changes so slowly that it remains a tempting target all month.

To take advantage of this Pluto viewing opportunity, you'll want to use an 8-inch or larger telescope. Although expert observers under excellent conditions have spotted the speck of light through 5-inch scopes, the added light-gathering power of larger instruments makes the task far easier. If you don't have a telescope big enough, consider hooking up with a member of a local astronomy club who does.

Once you've got your gear ready, line up a first-class observing site. For Pluto hunting, this means one that offers a dark sky as well as good seeing conditions. You'll get steadier eyepiece views if you look out over a grassy field or a wooded expanse. Don't aim your scope over areas that absorb the Sun's heat in daytime and reradiate it at night, such as asphalt parking lots or your neighbor's house.

Just as the lights of a city or town can drown out Pluto's glow, so too can the Moon's natural illumination. Try to observe when our satellite is out of the sky, preferably within a week or so of the July 15/16 New Moon (fittingly at the same time that New Horizons will be sending its most detailed images).

Once the night you've targeted for your search arrives, plan to reach your site by sunset. Set up your scope right away so it can start to cool to the air temperature. In the hour or so this process takes, your eyes will adapt to the darkness.

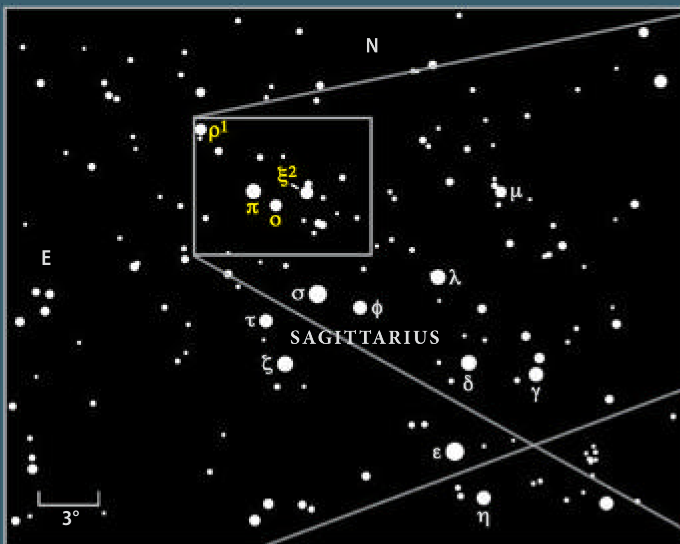
Sliding through the Archer

Now you are ready to search for Pluto. Use a dim red flashlight to illuminate the charts on the opposite page. Starting with the naked-eye view at top left, home in on a triangle of bright stars in the northeastern part of Sagittarius the Archer. Pi (π), Omicron (o), and Xi^2 (ξ^2) Sagittarii lie due north of the handle in that constellation's conspicuous Teapot asterism.

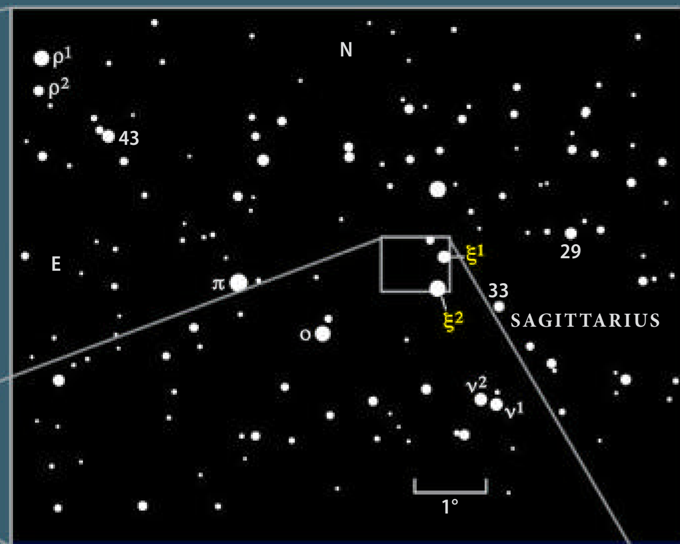
Use magnitude 3.5 Xi^2 as an anchor to star-hop to Pluto with the help of the telescopic view (bottom). We plotted the planet's positions during the evening hours for North America. The chart shows background stars to magnitude 14.5, so you should be able to discern Pluto. If you can't tell which point of light it is, sketch five or six stars near the correct position. Then return to the same field a night or two later. The "star" that moved is Pluto. Don't expect to see the cratered landscape that New Horizons likely will reveal. Instead, simply marvel at your ability to see this dim and no longer quite so mysterious dot from across the solar system.

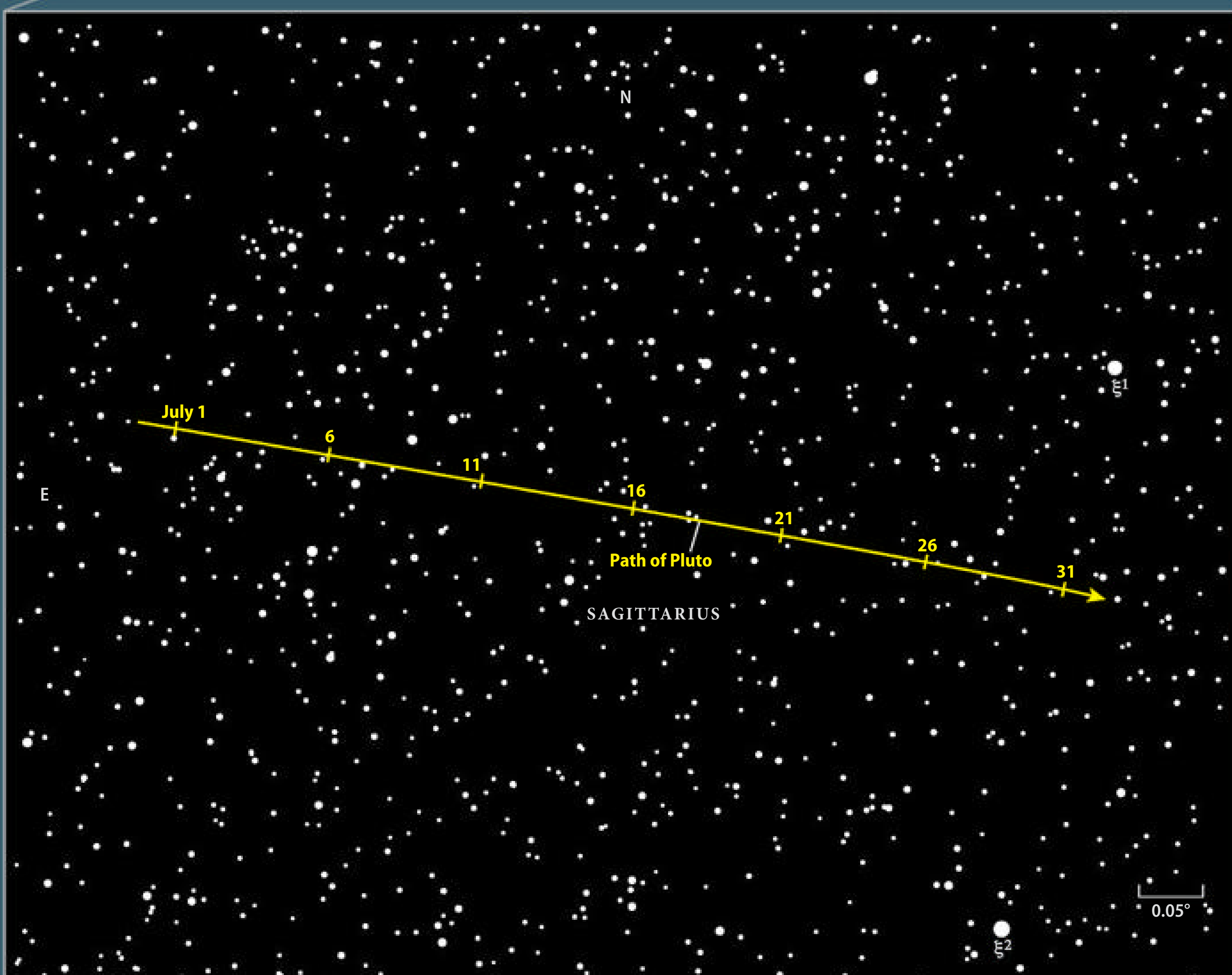
Richard Talcott *is an* Astronomy *senior editor and author of* Teach Yourself Visually Astronomy *(Wiley Publishing, 2008).*

This naked-eye view shows the stars of Sagittarius to magnitude 6.2. Pluto lies in the constellation's northeastern part, within a group of 3rd- and 4th-magnitude stars: Pi (π), Omicron (ο), and Xi[2] (ξ[2]) Sagittarii.



This binocular view shows stars to magnitude 8.5. Use it to pinpoint magnitude 3.5 Xi[2] (ξ[2]) Sagittarii, the brightest star close to Pluto, and its magnitude 5.1 neighbor, Xi[1] (ξ[1]) Sgr.





ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

Pluto begins July 0.8° north-northeast of Xi[2] (ξ[2]) Sagittarii and closes the month 0.3° north of it. This chart shows stars to magnitude 14.5.

Set your sights on the Great Rift

This unrelenting chain of dark nebulae is mightily impressive when you know what to look for.

by Alan Goldstein

What is the largest celestial object visible in the sky? If your answer is the Orion Nebula (M42), the Andromeda Galaxy (M31), or the Large Magellanic Cloud, think bigger. It's the Milky Way. The view we have of our home galaxy creates the largest object we can see. It only can be seen in its entirety in space, where Earth isn't in the way. Fortunately, earthbound observers with dark skies and a wide horizon can still get an impressive view. And weaving among the bright stars is an often overlooked area astronomers call the Great Rift.

The Great Rift is best seen in the evening sky during summer in the Northern Hemisphere and winter below the equator. This series of overlapping dark nebulae stretches from near Deneb (Alpha [α] Cygni) in Cygnus the Swan southward through Sagittarius and Scorpius before disappearing completely in Centaurus. That's an amazing 120° of the sky! It is so large that stargazers forget about it as a distinct celestial object. Many observers target the wonders sprinkled around it like gems on a strand while ignoring the unique splendor that defines the necklace itself.

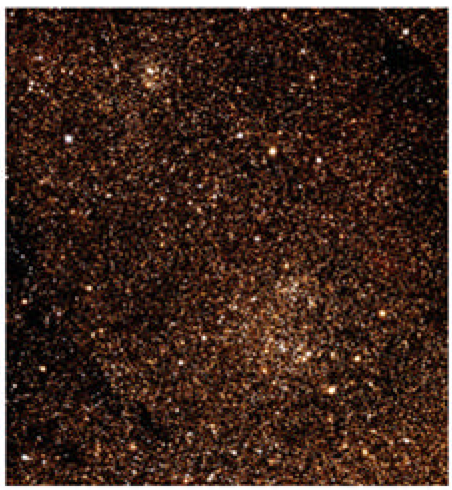
The reality of the rift

Dark nebulae mark the eventual birthplaces of stars. In addition to dust, they contain hydrogen, carbon dioxide, nitrogen, ammonia, and other molecules. They block visible light, making them blacker than the background glow of stars and the ionized hydrogen within bright nebulae. The Great Rift has the mass to produce a vast number of stars, but star formation

Alan Goldstein *is a longtime deep-sky observer who does most of his telescope viewing from locations near Louisville, Kentucky.*

This all-sky image of the Milky Way shows the extent of the Great Rift. It stretches from the constellation Cygnus in the north (left on this image) to Centaurus in the south. AXEL MELLINGER

The region around the star Sadr (Gamma [γ] Cygni) is where the Great Rift begins to divide the Milky Way into two streams. TERESA HAWES AND PHILIP DARLING/ADAM BLOCK/NOAO/AURA/NSF



In Aquila, the open clusters NGC 6755 (larger, center) and NGC 6756 lie on one side of the Great Rift, but much farther from us. BERNHARD HUBL

The combination of emission nebula NGC 6820 and open star cluster NGC 6823 are visible only because of openings within the Great Rift in the constellation Vulpecula. GERALD RHEMANN

requires a trigger (like a supernova shock wave) to get the process started.

Because the Great Rift is not a single object, its components lie at varying distances from us. Where it obscures the hub of the Milky Way in Sagittarius, the cloud is closest, about 300 light-years away. This distance increases as one moves north. In Cygnus, it approaches 3,000 light-years. As the distance increases, the width and sharpness of the nebulae's borders increase. That's why it splits our galaxy more conspicuously in the Swan. It helps define the spiral arm where the Sun resides.

The Great Rift has been an object of admiration as long as humans have gazed at the night sky in wonder. In some cultures, such as the Inca and Aboriginal, dark nebulae actually defined some constellations. But it is surprisingly rare to find observational descriptions of the rift in literature. The only comment T. W. Webb made in his 1859 classic, *Celestial Objects for Common Telescopes*, is slim: "The Galaxy near Gamma [Cygni] begins to separate into two streams."

The best way to take in the immensity of this unlit object is with your naked eyes. Find the darkest skies available, and get a reclining chair or blanket so you can relax and look up. Watching the Milky Way ascend under a truly dark sky is memorable. The Great Rift seems to "delay" our rising galaxy as if only a portion sneaks above the horizon — then it darkens — only to climb a second time.

The undulating border between the "solid" milky granulation of distant stars and the charcoal nebula is best observed through binoculars. Using both eyes is a boon when you sweep back and forth, allowing for the light-sensitive rods to pick up details. The foreground stars between the Great Rift and us distribute evenly, so try to ignore them and concentrate on the contrast of the background.

The dust clouds meander from east of the Cygnus Star Cloud, where it is a tight 5° thick. Clipping Sagitta, then nicking Zeta (ζ) Aquilae, the Great Rift dramatically broadens into Ophiuchus, west of the Scutum Star Cloud, where it becomes an impressive 20° wide (which equals the space from your thumb to your little finger,

The widest section of the Great Rift lies in this impressive region of emission and dark nebulae. The bright area to the right is the Eagle Nebula (M16), the Swan Nebula (M17) lies at center, and the small dark nebula Barnard 92 is to the left. JOHN A. DAVIS

The Rho (ρ) Ophiuchi region, which winds through the constellations Ophiuchus and Scorpius, is perhaps the sky's finest combination of emission, reflection, and dark nebulae. South of here, the Great Rift begins to break apart. ADAM BLOCK/NOAO/AURA/NSF

both extended at arm's length). It becomes less distinct in Sagittarius, where it is closest, breaking up into overlapping clumps. High-resolution imaging reveals that some of the rift is dark cirrus-like nebulosity across the center of the Milky Way above the galactic plane.

Using a rich-field telescope with low magnification can open a wealth of detail. You'll find places where the background Milky Way subtly dims because of foreground dust, while other areas have sharper edges. Use star charts that define the Great Rift to determine for yourself how closely they match your observation.

Dissecting the dark

Starting from the distant reaches where the Great Rift terminates near Deneb, emission nebulae ranging from the North America Nebula (NGC 7000) to the Gamma (γ) Cygni complex surround it on two sides. The motley open cluster M29 appears to be in contact with it but lies beyond at a distance of 4,000 light-years.

Dropping south from Cygnus into Vulpecula the Fox, open cluster NGC 6885 and the Dumbbell Nebula (M27) follow the Great Rift's southern edge. The former is about 2,000 light-years away on our side of the dark cloud, while the latter is some 600 light-years closer still. Holes in the dark nebulosity in Vulpecula let several distant

FRED CALVERT/ADAM BLOCK/NOAO/AURA/NSF

Dark nebulosity abounds in this wide-field image, except in the center where the Small Sagittarius Star Cloud (M24) shines through.

Baade's Window is a break in the Great Rift, which allows us to see objects much farther away. It's the brightest section of this image, just above the spout of the Teapot asterism in Sagittarius. BILL AND SALLY FLETCHER

objects shine through. The nebula and open cluster complex of NGC 6823 and NGC 6820 (at 6,000 light-years away) as well as open clusters NGC 6830 (5,300 light-years) and NGC 6802 (3,600 light-years) are among the most prominent. The Coathanger or Brocchi's Cluster (Collinder 399) is much closer than the rift at an estimated 420 light-years.

South of Zeta Aquilae is a V-shaped darker cloud at the front of the rift. The dark area pinches at the Aquila-Serpens border near the large open cluster IC 4756, a neighbor located 1,300 light-years away. On the opposite side, the double cluster NGC 6755 and NGC 6756 lie an estimated 4,900 and 5,000 light-years distant, respectively, far beyond any part of the rift.

The broadest portion of the dust complex lies above the galactic equator near Alpha Scuti and the Eagle Nebula (M16). The only notable deep-sky objects are a pair of tiny globular clusters hovering above and 20° northwest of the center of the Milky Way. NGC 6517 and NGC 6539 are 35,000 and 25,000 light-years away, respectively. You can spot them near the central bulge of our galaxy. Dense dust clouds dim the clusters considerably, else they might be 2.5 magnitudes brighter.

In Sagittarius, windows into the hub of the Milky Way, the most spectacular being the Small Sagittarius Star Cloud (M24), swamp the Great Rift. All that remains to define it are varying amounts of dark on all sides. The main band of the rift straddles M24 and open cluster M23.

The nearest part of the rift spans an area north of Sagittarius' Teapot asterism stretching toward Antares (Alpha Scorpii). Large dust clouds resemble galactic Rorschach inkblots in the heavens. The famous V-shaped Rho (ρ) Ophiuchi nebula complex is one example. The southernmost part of the Great Rift breaks apart south of Scorpius, in Ara and Norma, and disappears completely in Centaurus.

The rift among the spiral

The Milky Way is a puzzle made difficult to interpret because we are in its midst. The Great Rift spans several arms. We are located in the Orion Spur, between the Sagittarius and Perseus arms. The Cygnus Star Cloud appears bright because we are looking down its length, much like streetlights look in front of or behind the driver, whereas the closer lamps appear to be more widely spaced. The dark split is more concentrated (like smoke) at the greater distance, which, considering the overall dimensions of our galaxy, is still close.

Other star clouds shine through gaps in the Great Rift. The Sagittarius Star Cloud is part of the Sagittarius spiral arm, located inward from ours. The dust clouds break up to reveal openings into that arm, such as around M24 and Baade's Window near Gamma Sagittarii (with the double globular clusters NGC 6522 and NGC 6528).

The Scutum Star Cloud is a window in the rift that reveals a small portion of the Scutum-Centaurus Arm. At the southern extremity of the rift is the Norma spiral arm. Behind it is the Milky Way's bar-shaped central hub. We would have a much better view of the spiral structure if it were not obscured by dust, much like an highway interchange on a foggy night.

Capitalize on a dark sky

When you observe the Milky Way from Cygnus to the southern horizon, which is Scorpius for most Northern Hemisphere stargazers, the dark nebulae forming the Great Rift vary in density and size. Your ability to discern detail depends on a dark sky. If the galactic band is bright and its subtleties are plain to see, start looking at the big picture. That is where the Great Rift shines — or rather doesn't shine!

Stars form from dust and gas and give off dust and gas when they die. Your appreciation of this "galactic circulation system" will be strongest when you see them together. Whether you stick with naked-eye observations or view through binoculars or a rich-field telescope, it is humbling to think about the dynamics of our home galaxy and how our existence is founded on the interaction of gravity, dust, and gas.

SEE IMAGES OF MORE DEEP-SKY OBJECTS IN AND AROUND THE GREAT RIFT AT **www.Astronomy.com/toc.**

CATCH SOME MOON RAYS

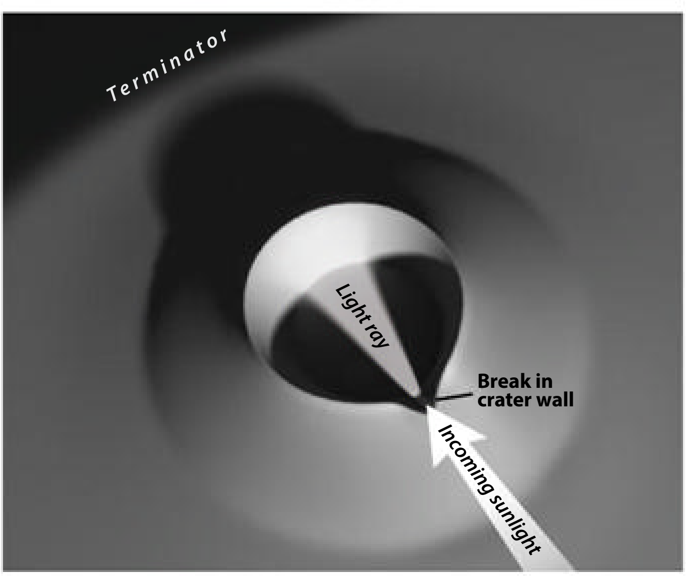
Turn your scope toward a crater on the Moon, crank up the power, and hope for illumination. **by Vincent S. Foster**

Calling all lunar observers, especially longtime ones. You probably have checked off all the major craters, counted craterlets to test your telescope's reach, pinpointed the Apollo landing sites, seen the Lunar X, and more. You wonder if there are any remaining challenges on our satellite for you to see. Then you read this story's title and think it will be describing material ejected from craters that resulted after meteorites struck the Moon's surface. Not even close. Mr. or Ms. Observer, meet lunar light rays.

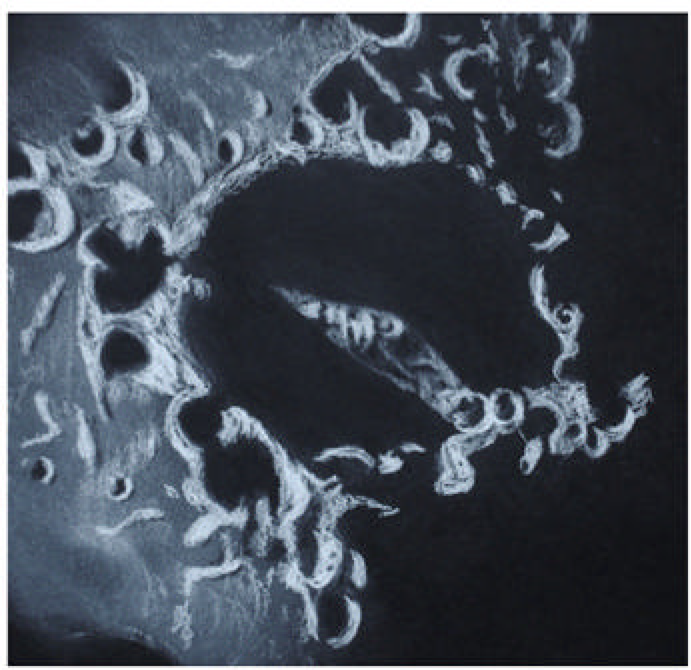
Lunar sunrise and sunset rays are rare phenomena that become visible when shafts of sunlight shine through gaps in crater walls or mountains. When the time is right, generally such openings can cast a spike of light across a crater floor that otherwise lies in darkness. They happen infrequently and only when the Sun hangs low in the lunar sky at sunrise or sunset.

The rays can range from thin slivers of light to triangular patches of illumination. And you won't always observe them within craters. A few sunrise and sunset light rays form exterior to craters, albeit by the same process. Sunlight passes through an opening and forms a ray on the dark plain (which lies in shadow usually because the crater wall is high) just outside a crater.

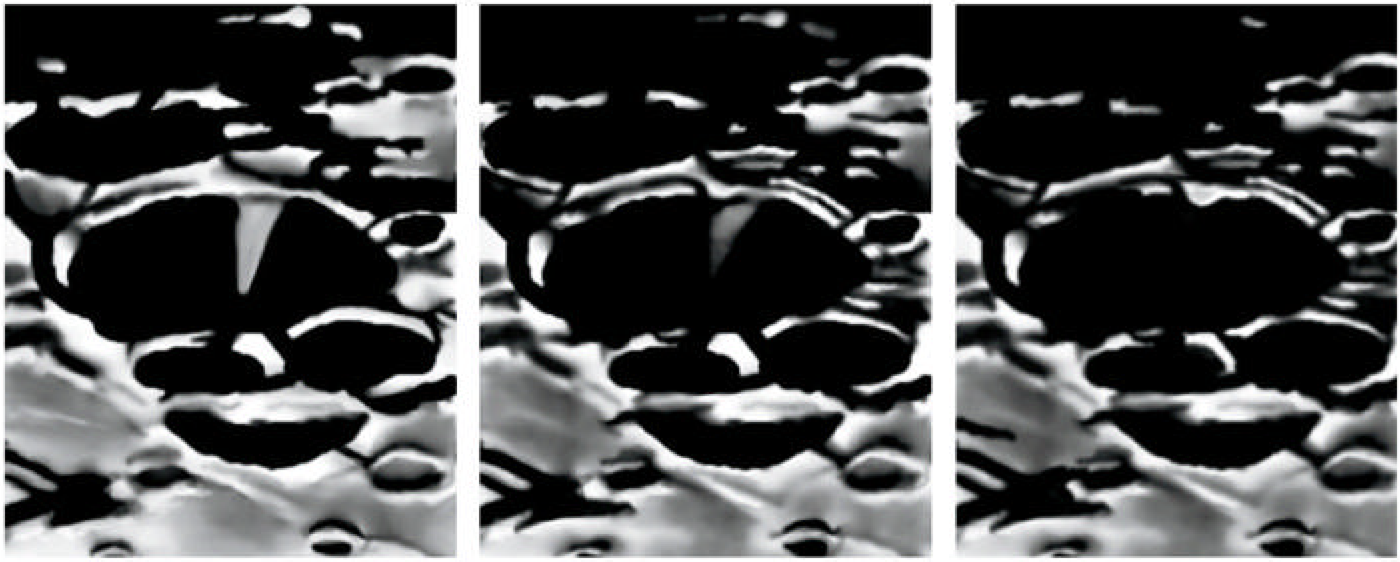
According to lunar astronomers, a true lunar light ray is one that crosses up to 3° of longitude while being less, on average, than ¼° in latitude width. Because of the combined geometry



This illustration shows the most prevalent way lunar light rays form. When the Sun stands low in the lunar sky at a crater's location, the crater floor lies in shadow. A break in the crater's wall, however, may allow sunlight to spread out in a ray pattern, illuminating part of the darkened floor. If the break is on the opposite side of the crater, the light ray will brighten a region outside the crater. *ASTRONOMY*: ROEN KELLY



This detailed sketch of Maginus Crater shows a sunrise ray illuminating part of the crater's floor as well as a craterlet on the far wall. THOMAS McCAGUE



The sketcher reported, "My attention was captured by the remarkable illumination of Zeno's floor; most of it was in shadow save for an illuminated triangular section. This was even more remarkable because of a dark shadow bisecting the eastern inner wall of Zeno A, almost in line with the ray. To depict the changing illumination of the area, I made a second sketch an hour after the first. By 1h05m UT, the ray had faded considerably, the narrowing illuminated section of Zeno's floor appearing duskier toward the west, and the edges of the bounding shadow were less distinct than before. A third observation, made between 1h40m UT and 1h50m UT, saw Zeno's floor completely in shadow." PETER GREGO

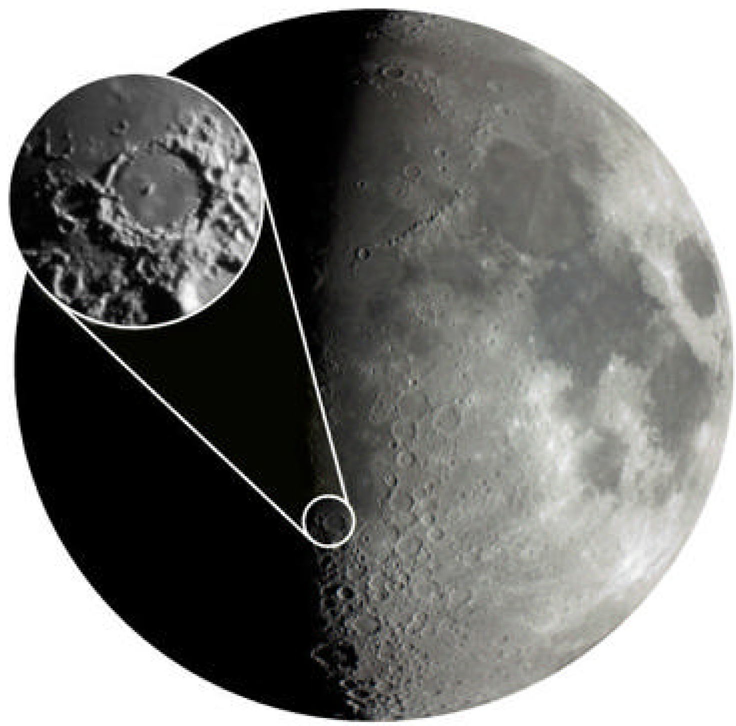
involving the Sun, the Moon, and our viewing angle, they are usually short-lived and occur within only a two- to three-hour window of opportunity.

Although astronomers first observed lunar light rays more than 150 years ago, they gained popularity only in the mid-1990s when reports of them began appearing in amateur astronomy publications. Since then amateur astronomers have discovered dozens of craters where sunrise or sunset rays shine through a crumpled or broken crater wall and create these light shows lasting only a few hours.

The only way to detect lunar light rays is by scanning with your telescope along the lunar terminator (the line dividing the lit part from the dark section). If you're lucky, you just might spot one. For those who prefer not to leave it to chance, the CalSKY website (www.calsky.com) can calculate sunrise and sunset times along with the Sun angle to determine which lunar craters will display light rays and when.

After inputting your geographical coordinates, you need to enter the date, time, and duration you wish to observe. CalSKY then will generate a list of craters exhibiting rays, including date and time of visibility, together with a map showing the crater and observer reports describing the lunar light ray. When the website first appears on your monitor, click on the headings "Moon" and then "Phenomena, Light Rays."

As of this writing, observers have identified and confirmed 82 lunar light rays. Admittedly, some of them are really difficult to see. A few craters have dual entries, one each for sunrise and sunset rays. Oh, and here's a note to some and a reminder to others: Sunrise occurs at the terminator between New Moon and Full Moon — in other words, when our satellite rises before sunset occurs on Earth; sunset at the terminator occurs between Full Moon and New Moon, or when the Moon rises after sunset on our planet. The 21 lunar light rays that we highlight on the two Moon maps on p. 54–55 are among the most prominent.



The smaller image zooms in to reveal a well-defined sunrise ray in Hesiodus Crater, which lies to the left of the larger crater. STEFAN SEIP/ASTROMEETING.DE

You'll find a complete list of all 82 lunar sunset and sunrise rays at the website of the Robinson Lunar Observatory at http://tinyurl.com/lunarrays.

Although observing lunar light rays yields no scientific value, the rarity of these events, coupled with the short time frame they are visible, makes them real challenges for the avid lunar observer. That alone is usually enough to get us off the couch and under the stars. So if the sky is clear, go catch some rays!

Vincent S. Foster *has been an amateur astronomer for more than 50 years. He chairs the Hydrogen Alpha Solar and Bright Nebulae Observing Programs for the Astronomical League.*

AFTER **FULL MOON**

Try to locate these lunar light rays between Last Quarter and Full Moon. Remember to only search for light rays when the specific crater lies near the terminator. North is up. JOHN CHUMACK

BABBAGE RAY
The ray is a moderately broad pie-shaped swath of light that illuminates the crater floor. It emanates from the southeast corner of Babbage, along the wall next to South Crater.

BONPLAND RAY
A thin ray crosses the high plains of northern Bonpland Crater from a break in the western rim of neighboring Parry Crater. It is hair-fine and extends some 15 miles (25 kilometers) to the west where the tips of the shadowed peaks meet the depths of blackness at the terminator.

KIES RAY
At sunrise at Kies Crater, a rather wide swath of light emanates through a broken segment of the western rim. The light ray narrows abruptly (due to the position of a ridge it falls on) just before the point where it would fade into the terminator. A few minutes later, the ray widens and spills into a shallow, wide trench between Mercator Crater and Koenig Crater.

MERCATOR RAY
Within Mercator Crater, a small but fat triangle making up the lunar light ray shines on the western rim just south of craterlet Mercator C and directly across from craterlet Mercator B.

HESIODUS/PITATUS DOUBLE RAY
This is the ray that jump-started the surge in interest in lunar sunrise and sunset rays in recent years. The wall between these two craters has a deep cleft. At sunrise there, a ray crosses Hesiodus' floor. At sunset, a ray crosses Pitatus.

VIETA RAY
This sunrise ray is large and cone-shaped. It fans out and extends to Vieta Crater's western wall. Except for the ray, the entire floor is in shadow.

CURTIUS RAY
When the Sun rises at Curtius Crater, light shines through a crack in the eastern wall, causing a triangular patch of illumination to cross the crater floor and fall onto the western rim.

LONGOMONTANUS RAY
A broad shaft of light spreads out in width from slightly west of Longomontanus Crater's central peak to its floor. Because of the shadow the central peak casts, the light ray takes on a distinctive C shape.

SCHEINER RAY
This sunrise ray is a short, thin shaft of light originating north and west of the craterlet Scheiner C. Here, Scheiner A's western wall casts a shadow that forms the southern border of this lunar light ray.

BEFORE **FULL MOON**

Although you might spot a lunar light ray near the terminator at any phase, a few days before to a few days after the First Quarter Moon offer a lot of prospects. North is up. JOHN CHUMACK

BARROW RAY
Observers have viewed a thin but long shaft of light crossing the floor of Barrow Crater at sunrise there.

BURNHAM RAY
This sight comes from a low area or break in the western wall of Burnham Crater at sunrise there. The ray then extends across the low plain to the west of the crater between it and the terminator, rather than across the crater's floor.

HYPATIA DOUBLE RAY
This double ray forms when sunlight passes through a cleft in Hypatia Crater's eastern wall, which creates a ray shining across its floor. A second ray shines through a cleft in the western wall and falls across the terrain to the west of the crater.

HALLEY RAY
The Halley Crater ray occurs at sunrise and sends a thick spike of light across the crater floor.

PTOLEMAEUS TRIPLE RAY
During sunrise at Ptolemaeus Crater, a subtle shading may appear. This streak of gray can turn into three shafts of illumination extending across the crater's floor, which otherwise remains in darkness. These rays illuminate the gently undulating terrain of the Cayley Formation.

VOGEL RAY
A sunrise ray crosses the floor of Vogel Crater, starting as a thin triangle of light that progressively thickens.

WALTER RAY
The Walter ray is a fairly dramatic shaft of light that crosses the floor of Walter at sunset there. A gap in the crater wall casts a spreading wedge of light across the floor. At high power, you may see a small craterlet near the gap looking like a tiny crown casting three-pointed shadows across the floor toward the central peak.

ORONTIUS RAY
During sunrise at Orontius Crater, a thin shaft of light crosses its floor along the north rim of the crater.

GEMMA FRISIUS RAY
This sunrise ray is the result of a break in the eastern wall of this southern highlands crater, which allows a shaft of light to shine across the crater floor and illuminate the three smaller craters on Gemma Frisius' western rim. Some tiny ridges — only several feet in height — cause this ray to have a few dark bands in it roughly perpendicular to the ray.

STÖFLER RAY
This lunar light ray forms because of a gap in Stöfler Crater's eastern wall. It starts halfway between craterlets F and K and stretches halfway across the main crater's floor.

MAGINUS RAY
This wedge-shaped ray crosses the darkened floor of Maginus Crater westward from a break in the eastern wall. As you continue to watch, this sunset ray will broaden and bring more of the crater floor into view.

MAUROLYCUS RAY
At sunset, the top of Maurolycus Crater's central peak is still in sunlight. The light ray appears as a thin, bright streak between the eastern wall and the central peak.

The nature of observing

Want to see the Orion Nebula's hidden colors? First, take a walk outside to watch flowers in the moonlight.

by Stephen James O'Meara


To see colorful nebulae and the faintest objects, first learn to observe nature.
PANARAMKA/ISTOCK/THINKSTOCK

VISUAL OBSERVING CAN BE EITHER A PASTIME OR AN ART. Both are fine, and it's your choice. But if you desire to see faint stars and nebulae or fine lunar and planetary details, or if you want to penetrate the veil of normal vision, push the limits of your telescope, or perhaps one day see what no one has seen before, then observing the world around you — both in the daytime and at night — can help.

The "art" of observation

You don't need to be behind the eyepiece to improve your observational skills. You can start right now by studying your immediate environment — repeatedly, until you feel you've exhausted your visual capabilities. Let's start with how to use direct vision to improve your observing skills.

Direct vision relies on your eyes' 6 to 7 million cones that work best in bright light. Cone cells are dense in a little dimple in the center of the retina called the fovea; this small region is responsible for most of the eye's color perception (more on that later). It is also the location of the eye's sharpest vision. So if you want to train your eye to see fine lunar and solar features, you need to master direct vision, not averted vision. You can do this right now, no matter where you are.

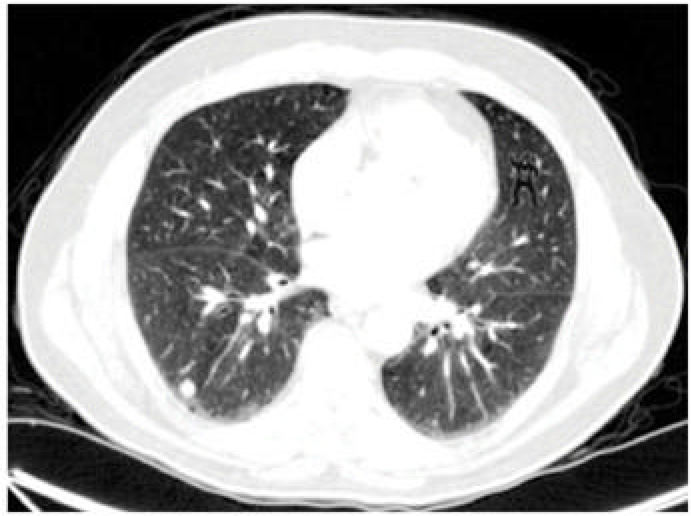
For instance, as I write this I'm looking directly at a section of rug beneath my feet. It's a square, tan-colored rug with an interlaced V-shaped pattern throughout. The rug has a khaki border with a tiny tear at one corner and faint stitching running along its inner edge. Can I see more?

To find out, I take a second look. This time I see everything I noticed in my first look but in only a fraction of the time. My eyes then start looking for something new, something I might have overlooked. The first thing that stands out is a tiny white stain in the rug near the torn corner; that corner is ever so slightly curled up.

I look away, breathe, and then repeat the exercise. As before, everything I had noticed previously comes quickly into view. My eyes start probing ever deeper for finer

Stephen James O'Meara *is a contributing editor of* Astronomy *who authors the "Secret Sky" column each month.*

The blue hour happens just before dawn and right after sunset. Train your eyes to see color in bright nebulae by careful observation of flowers during this magical time of day. BOZHDB/ISTOCK/THINKSTOCK



See anything odd in this CT scan of a human lung? Most radiologists don't. Art courses are increasingly offered to help medical students see fine detail through repeated visual inspection. MELISSA VO, TRAFTON DREW, AND JEREMY WOLFE

details. It works. When I look directly at the torn corner, I see a tiny white thread in it. I could go on. The point is, by repetitively studying everyday ordinary items in your environment, you can improve your direct observing techniques and apply them when looking through the eyepiece.

Medical students across the nation have embraced the fact that repetitive visual inspection can enhance one's ability to see exceptionally fine detail. Universities now offer innovative courses to help future physicians "learn how to look" through the study of art. The students repetitively inspect works of art to hone their critical observation skills, which could make all the difference when it comes to interpreting, say, an X-ray or MRI or making an accurate diagnosis. One study in the *Journal of the American Medical Association* notes that medical students showed about a 10 percent improvement in their ability to detect important details after taking these courses.

Just as paintings become surrogate patients for young doctors, repeated visual observations of anything from artwork to rugs can serve as surrogate telescopic objects for you to hone your own observational skills. Next, let's look outdoors after sunset to help you better understand how your eyes work under different lighting conditions.

Bewitching twilight

The nature of observing starts with observing nature — magic happens every day in the open air. With so many natural phenomena occurring, it's difficult to watch them all. But there's one that may be of particular interest to observers. Called the Purkinjě effect, this bewitching color shift occurs during the morning and evening twilight and can help you determine how sensitive your eyes are to color in low light.

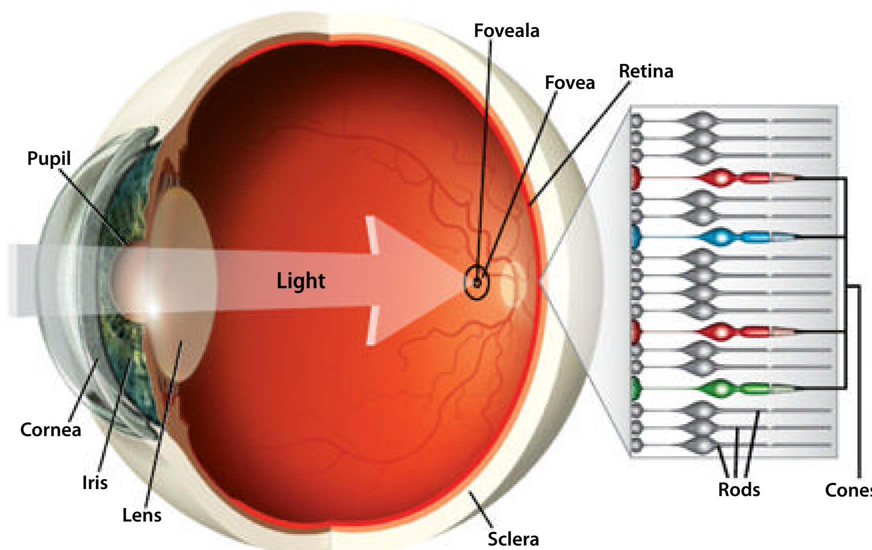
Czech physiologist Jan Evangelista Purkinjě (1787—1869) discovered the phenomenon in the dawn while walking and meditating. Of it, he wrote: "Objectively, the degree of illumination has a great influence on the intensity of color quality. ... Particularly the brightest colors, red and green, appear darkest. Yellow cannot be distinguished from a rosy red. Blue became noticeable to me first. ... Green appears more bluish to me, and its yellow tint develops with increasing daylight only." The sequence happens in reverse after sunset.

In other words, two objects of opposing hues (one red, one blue) under bright light appear equal in intensity. But as the light diminishes, red fades while blue brightens.

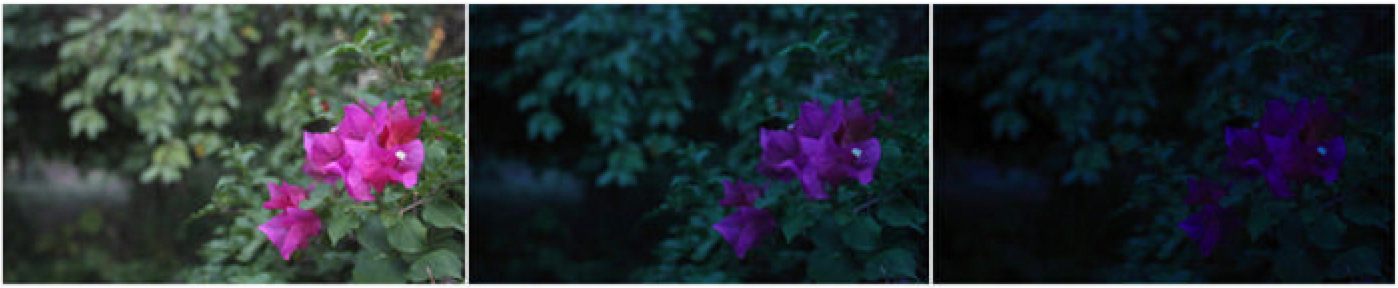
To study this color shift, I suggest going out before the Sun sets and recording the color of different flowers, noting say, (on a scale of 1 to 5) how well they stand out against their leafy backgrounds. Particularly observe the contrast between flaming red flower petals and dark green leaves.

Continue to observe the flowers as twilight deepens, and record what happens.

Your window to the universe



Light enters the eye through the pupil and hits the retina. In the center of the retina is a dimple called the fovea, which gives the eye most of its color perception. So, in order to see fine lunar and solar features, an observer must master direct vision, not averted vision. *ASTRONOMY*: ROEN KELLY



As twilight gives way to moonlight, try to record the changing intensity of colorful flowers like those imaged here by the author. You might notice that while reds will fade, blues actually grow brighter in the diminishing light. STEPHEN JAMES O'MEARA

You'll be observing in the magical "blue hour" well known to photographers because the sky's color creates a superluminous light that makes flowers appear to fluoresce.

The blue hour starts about 10 to 15 minutes after sunset and lasts about 30 minutes, making it more of a blue half-hour. (To find the blue hour at your location, go to www.bluehoursite.com) Generally, there's only a brief period when the colors achieve maximum intensity, but it is undeniably glorious under perfect atmospheric conditions. Because everyone's eyes perceive color and light changes differently, it is difficult to say exactly what you'll experience.

Understanding the Purkinjě effect will help you perceive color in deep-sky objects, such as the reds and greens of the Orion Nebula or the pale blue and aqua hues of bright planetary nebulae. So controversial are these colors at times that the only way for you to be certain of your observation is to have absolute confidence in your ability to perceive dim color at night. You can achieve this through visual training — by studying flowers and watching how deep into twilight you can follow their colors and at what point they disappear. Repeat observations will build confidence.

Working the night shift

As night falls, turn your attention to one of the brightest flowers. Look directly at it, and watch how it fades. Next, move your gaze slightly so the flower is just off center, and see how brightly it glows at the periphery of your vision. That's because the flower's light is falling on the eye's night-sensitive rod cells, some 120 million of which line the retina.

Rod cells require 30 minutes to become well adapted to darkness. During that time, the sensitivity of the eye increases by a factor of roughly 10,000. The rods are densest in a ring surrounding the fovea, but that region is not necessarily the most sensitive to faint light.

Repeat this observation several times, being careful to record how you avert your gaze: Where must you look to make faint objects appear brightest in your field of view? I tend to place the object of study toward the upper left from the center of my field of view, which places my direct vision down and to the right — all the while, I keep my attention focused on the object of study, even though I'm not looking directly at it.

The colors of the cosmos seen through an eyepiece will never come close to those seen in Hubble Space Telescope images, but by training your eyes, you can learn to see shades like those shown in this Orion Nebula sketch. ERIKA RIX

Repetitive "averted vision" investigations should reveal your eye's primary retinal "hot spot" — a region where night-sensitive rods work together most efficiently to make dim objects appear their brightest. Knowing how to position deep-sky objects (barely visible galaxies, dim nebulae, or clusters of faint stars) on your primary retinal hot spot is arguably the most important factor in making observations at the limit of vision.

The second most critical factor is your confidence level. You acquire this certainty by passing the dim object of interest over your retinal hot spot repeatedly until you feel 100 percent confident of its reality. In my opinion, there is no middle ground; I either see an object, or I don't.

Time to zero in

If you want to push the limits of your vision to its fullest — to learn not only how to see dim objects at night but also to eke out details in them — you can practice far from city lights under the soft glow of a First Quarter Moon.

When I look at flowers in the moonlight, I notice that they have a variety of textures. Under this peaceful light, my eyes move rapidly in such a way that a flower starts at the 2 o'clock position in my field of view, moves down and to the lower left toward the outer boundary of the fovea, then down and to the right to my 4 o'clock hot spot, before I rapidly repeat the inspection over and over.

This sweeping process — perfected by observing Mother Nature — helps me view fine details in, say, a galaxy or nebula through a telescope. After placing the object in my retina's hot spot, I gently sweep it toward the boundary between the inner edge of the retina's periphery and the outer fovea. When I do, the dimmest sections of the object disappear, leaving behind the brighter details. I record these features and then sweep the object back to my hot spot, where I can see and note the faintest details.

By continually sweeping the object back and forth across the retina's rods and cones, I can critically inspect both the brightest and faintest regions and realize the object's most intricate visual secrets. Stripped of its veil of mystery, the object surrenders itself. As Henry David Thoreau observed, "Nature will bear the closest inspection. She invites us to lay our eye level with her smallest leaf, and take an insect view of its plain."

Vacation with the stars

If you've got some time off, check out these great astronomy travel ideas. **by Tom Trusock**

Who doesn't need to get away from it all once in a while? I could use a break, and you probably could too. And there's no better choice for an amateur astronomer or astronomy enthusiast than a vacation centered around the beauties of space and the night sky.

No matter your budget or time constraints, it's always possible to design a memorable astronomy vacation. If you're planning a big trip, you can choose the do-it-yourself option or book a complete package with a tour company. Whether you prefer an overnight stargaze at your favorite nearby park or a lavish observing adventure on the opposite side of the globe, there's something for everyone. While I haven't checked every one of the following experiences off my personal bucket list, here's a selection of some great astro-destinations and activities to get your planning started.

Tom Trusock *is a veteran observer who lives in Ubly, Michigan.*

Guided tours

Going with a well-established company that manages your entire itinerary might cost a bit more but will remove a lot of worry and uncertainty about visiting a distant locale. One highly regarded and well-recognized company is TravelQuest International. This Prescott, Arizona, based business specializes in astronomical trips, cruises, and tours. It has a history of nearly four decades in the business and offers a wide choice of vacations around the world. In addition, the company is working with *Astronomy* magazine to bundle noted speakers in with its trips. You can find a list of collaborative astro-tours on Astronomy.com.

TravelQuest offers one opportunity that is quite literally out of this world. While there are eclipse and auroral tours aplenty, they are now accepting flight bookings with Virgin Galactic, an enterprise working hard to become the world's first commercial spaceline. Priced at $200,000 per seat with a minimum deposit of $20,000, these early flights do not come cheap, but it would be an experience you'd remember for the rest of your life.

If you're looking for a more down-to-earth choice, TravelQuest has a number of attractive ground-bound tours for 2015/2016. The Norway Aurora, Culture, and Scenic Wonders tour catches my interest. Starting in Trondheim, you'll cruise the fjords for four days, and then gain firsthand experience of Lapland culture, both now and from times past. Spy reindeer on the tundra, and feast in the traditional style. What better way to view the northern lights?


Yosemite's monumental Half Dome is a geologic treasure, matched only by the incredible night skies permitted by its remote location, far from any city lights. ROGELIO BERNAL ANDREO

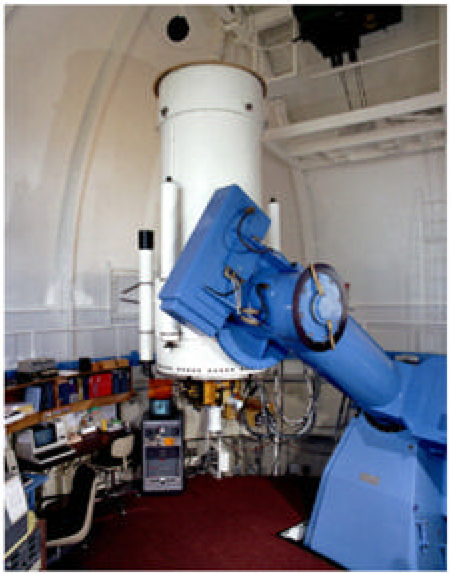
Borrow a bigger telescope

If you're not the type to let someone else do all your planning (or if your pockets simply aren't that deep), there are many other options. Want a chance to observe with some extremely large telescopes?

Out at California's Mount Wilson Observatory, you'll find the largest telescopes in the world devoted solely to public viewing. You can book the historic 60-inch reflector for visual observing in groups from two to 25 individuals — or go by your lonesome. Built with funds provided by Andrew Carnegie in 1908, the 60-inch was the largest telescope in the world for 10 years.

Viewing here doesn't just mean spectacular celestial sights; you'll also be walking in the footsteps of great astronomers. Noted researchers including Harlow Shapley, Edwin Hubble, Walter Baade, and Allan Sandage all used this workhorse scope. Reserving this treasure costs $900 for a half-night or $1,700 for the full night. For an even more decadent astronomy experience, Mount Wilson recently added the 100-inch Hooker Telescope to their public viewing program, at a rate of $2,700 per half-night or $5,000 per full night (18 people maximum). While these rates might be a little pricey for an individual, a club could find them more palatable. Just make sure to book well in advance.

Over in Arizona, you can check out Kitt Peak National Observatory. Its offerings run the gamut from nightly stargazing sessions for beginners and workshops on binocular observing (the observatory will be happy to provide the equipment) all the way up to advanced imaging and overnight programs. You also can rent an observatory and guide for a three-hour session. And if big telescopes are your thing, be sure to check out the 0.9-meter public nights program, which allows visitors to


Kitt Peak National Observatory allows visitors to observe with the 0.9-meter WIYN Telescope, though it is also actively used as a research instrument. WIYN/NOAO/AURA/NSF

By night the aurora borealis will light up the sky, but by day the TravelQuest tour will lead you through Norway's mountain-ringed fjords along the Arctic Circle. KARRI FERRON

The Chacoan people paid careful attention to the skies above them. Like many of the ancient cities in Chaco Canyon, New Mexico, Pueblo Bonito is oriented along the cardinal directions so that during the equinoxes, the Sun rises and sets neatly in line with the major walls of the city. Chaco Canyon's modern observatory is thus a natural fit. NPS

Few of the telescopes atop Mauna Kea allow visitors inside (though Keck does have a public gallery), but the view from the summit alone is worth the trek. TOM KERR

observe through the WIYN Consortium Research Telescope.

Venturing further afield, there's always Hawaii. Friends of mine spend no little time bragging about the astronomical advantages of the Big Island and its telescopes. While there are lots of scopes on the island, unfortunately the Subaru Observatory is the only facility that has formal public tours still available. If you're thinking about going, be aware you'll need to sign up months in advance.

If you're unable to make Subaru (or while you're already there), the Keck Observatory has a public gallery that describes its research and lets you peek at the underside of the Keck I Telescope. In addition, the Mauna Kea Visitor Information Station, located 9,200 feet (2,800m) up the mountain, is open every day of the year from 9 A.M. to 10 P.M. and provides free stargazing programs outside the visitor station every night. It has an online calendar of events that details upcoming outreach sessions along with a Saturday program schedule. But be aware that the drive to the summit can be a bit rough! The visitor station halfway up makes for an easier trek, but for either destination, altitude should be taken into account; it's recommended that children under 16 do not attend.

Stargazing in the parks

Less expensive and a little closer to home, some of my favorite stargazing experiences have been in America's National Park System. Due to the abundance of lights and — worse yet — the ever-popular campfire, with its ability to scatter smoke particles across sensitive optics, campgrounds themselves usually are not the best for stargazing. However, walk down the path a short way, and you'll find the dark skies you crave. Many parks offer nighttime observing sessions, typically geared for beginners. Usually offered by park rangers, often with the assistance of local astronomy clubs or volunteers, these sessions are an accessible and inexpensive glimpse into near pristine dark skies. Check with the ranger station in your destination of choice for specific locations, times, and opportunities.

While we're on the subject of observing in the national parks, I'd be remiss if I didn't point out the following notable stargazing experiences.

The Grand Canyon Star Party, a joint effort between the Saguaro Astronomy Club, the Tucson Amateur Astronomy Association, and plenty of other astronomy clubs, runs for more than a week, traditionally in June, on both the north and south rims of the canyon. There's no better time to witness some of the most striking features of the heavens and Earth in one place.

While I've not been there, Chaco Canyon, New Mexico, is one of the few parks that has an actual observatory. Since 1991, the Chaco Night Sky Program has been educating visitors on the astronomical practices of the Chacoan people from over a thousand years ago, as well as using more modern approaches to view the night sky. In 1998, the National Park Service dedicated the Chaco Observatory, and in 2013 the park gained status as an International Dark Sky Park.

Even if there's nothing organized, I've found that bringing my own optics to darker skies than I have at home is an extremely worthwhile experience. Some of my personal favorites include Yellowstone in Wyoming, the Badlands in South Dakota, and various lesser-known parks like Isle Royale in Michigan and Great

Since 1984, the Florida Winter Star Party has been the site of dark skies, social and hobby experiences for stargazers from around the globe, scores of telescopes, and beautiful Florida weather. What better escape when you've got the winter blues? MIKE REYNOLDS

The Space Shuttle Program hurtled men and women into space and brought them home again for 30 years, and there's nothing quite like standing in the presence of one of these engineering treasures. Kennedy Space Center in Florida has housed *Atlantis* since its retirement in 2011. NASA

Basin in Nevada. Great Basin is probably one of the best-kept secrets for amateur astronomers. Take some of the darkest night skies in the United States, combine them with low humidity, low light pollution, and high elevation, and you've got a recipe for heaven. While there's no denying the grandeur of Half Dome, located in Yosemite National Park, California, there is also a distinct allure to staying a little more off the beaten path.

If you're looking for the ultimate low-cost astronomical stargazing vacation, be sure to check out any national or state forest in your neck of the woods. While it can take a little searching to find suitably unobstructed views for observing, these wilderness areas can offer unmatched skies and glorious isolation. Campsites are available for a nominal fee, but amenities are limited. To find the national forest nearest you, check out the U.S. Forest Service's interactive online visitor map.

Hot and cold states

High on my bucket list is an auroral tour in Alaska. There are many companies offering northern lights experiences. Most offer a complete package, but doing it piecemeal is certainly an option. One of the most popular destinations for basing a trip like this is Fairbanks. Its location makes it prime for northern lights observing while remaining relatively accessible. Some may shudder at the thought of winter in Alaska, with it's –40° nights, but spectacular aurorae make such a trip worthwhile for many.

At the other end of the country and the thermometer, consider the Florida option. The Winter Star Party (WSP), hosted by the Southern Cross Astronomical Society of Miami, is one of the most recognized star parties worldwide. The WSP is held way down in the Florida Keys around the New Moon in February. Again, make reservations and buy tickets well in advance.

That's not all there is to do in Florida. Big on any astro-nut's list should be the Kennedy Space Center (KSC) at Cape Canaveral. KSC offers several tour options: the KSC Bus Tour and a series of "Up-Close" tours. The Bus Tour provides an overview of the space center and is included with admission. The Launch Control Center Tour allows a peek into Firing Room 4, the room that controlled the 21 shuttle launches since 2006. The

Alaskan skies put on spectacular auroral shows for those brave enough to face the cold. MARTIN GUTH

Explore Tour includes views of launch pads, the Vehicle Assembly Building, the Shuttle Landing Facility, and more. And for history buffs, you won't want to miss the Then & Now Tour, which lets you explore the history of America's space program, hear its stories, and even touch a piece of another world.

We take vacations to step out of our everyday world and experience something new. We take them for relaxation and entertainment. We take them to revitalize and reinvigorate ourselves. Next time you take a trip, consider matching your getaway with your favorite hobby. What better choice could there be?

ONLINE RESOURCES

Check out these handy links for more information on some of the astronomy-related travel destinations mentioned.

Astronomy magazine Trips & Tours: **www.astronomy.com/magazine/trips-tours**
TravelQuest International: **www.travelquesttours.com**
Mount Wilson Observatory: **www.mtwilson.edu**
Kitt Peak Visitor Center: **www.noao.edu/outreach/kpvc**
Chaco Culture National Historic Park: **www.nps.gov/chcu**
Mauna Kea Visitor Information Station: **www.ifa.hawaii.edu/info/vis**
U.S. Forest Service interactive visitor map: **www.fs.fed.us/ivm**
Kennedy Space Center: **www.kennedyspacecenter.com**

Go light with the Star Adventurer mount

Sky-Watcher USA's mount is small, light, and accurate — plus, it won't break the bank. **by Mike Reynolds**

There have been many times when I wanted a lightweight, portable equatorial mount to use with a small telescope, Hydrogen-alpha (Hα) instrument, or camera when I was traveling. Those occasions when I braved taking a larger equatorial mount, especially when flying, were challenging to say the least. My wife would look at me like I was crazy: one suitcase for our clothes and three for the mount, tripod, accessories, and tools. When the airlines' luggage scale readout maxed out, I knew I was in more trouble.

A small, reliable mount for observing is always a nice piece of hardware to have if you're like me and enjoy escaping for an evening or weekend. Or perhaps you have a telescope and want to upgrade to a mount with the ability to track as you observe.

Sky-Watcher USA's Star Adventurer mount provides a highly portable option when you want to do some grab-and-go observing while still tracking what you see. SKY-WATCHER USA

First impressions

Sky-Watcher USA has designed and manufactured a portable German equatorial mount (GEM) called the Star Adventurer. What I saw right out of the box pleased me. The unit is lightweight, tipping the scales at a little over 2 pounds (1 kilogram) not including the optional counterweight ($30), which is a shaft with a 2.2-pound weight on it. All construction also was of high quality.

The Star Adventurer package normally includes a polar scope and illuminator. The one I tested also had some accessories: an adjustable wedge, the counterweight set, and a fine-tuning assembly for mounting a telescope. The Star Adventurer does not come with a tripod; I used medium- and heavy-duty photographic tripods for the review.

Note that Sky-Watcher USA makes two versions of this mount. The $339 Astro Package (the one I tested) has a declination bracket. The Photo Package, which retails for $20 less, comes with a ball-head adapter. That accessory allows you to easily attach a DSLR camera.

Setting up the mount is easy. I used the included equatorial wedge with the Star Adventurer GEM and the ⅜-inch threaded setup. The wedge lets you adjust the mount to your latitude for polar alignment, a must for when you want to track. Just make certain your tripod is sturdy enough that you don't pick up any unwanted vibrations.

The author attached his Canon DSLR and zoom telephoto lens to the mount, which carried the combo with little effort. MIKE REYNOLDS

I preferred to attach the wedge directly onto the tripod. Yet you could use a pan- or ball-head tripod setup if you want. Some of you might even use a pan- or ball-head as your wedge to adjust to the North or South Celestial Pole.

The mount has an excellent built-in polar alignment telescope. You calibrate it with a well-designed reticle with markings for both poles, making alignment easy. I recommend using the adjustable illuminator to light up the reticle. The mount also features a date dial to compensate for star drift over time.

The mount derives its power from either four AA batteries or a 5-volt USB port. The specifications noted up to 72 hours of continuous use with one set of AA batteries.

Mike Reynolds *is an* Astronomy *contributing editor and professor of astronomy and physics at Florida State College in Jacksonville.*

The motor is a DC servo type, the aluminum alloy wheel gear measures 3.4 inches (86 millimeters) in diameter with 144 teeth, and the brass worm gear is 0.5 inch (13mm) in diameter. I note these specs to support my conclusions about the quality; no plastic parts here.

Beyond the basics

As for mounting options, several are possible. You can use a ⅜-inch ball-head adapter for a camera-lens combination, allowing you to do tracked imaging with your camera. Sky-Watcher USA has additional ball-head adapters available so you can image with two cameras if you wish. I am thinking ahead to the 2017 total solar eclipse, and this might just be one of my imaging setups: two cameras with lenses of different focal lengths on a reliable GEM like the Star Adventurer.

Other optional setups include using a telescope with the Fine-Tuning Mounting Accessory or a telescope side by side with a camera on a ball-head. The manufacturer built a nice slow-motion adjustment into the Fine-Tuning Mounting Accessory. A counterweight and shaft can be used to balance a heavy telescope.

Low-battery and motor-error indicators are also a part of the system. Mount tracking rates include sidereal; 0.5x, 2x, 6x, and 12x sidereal; solar; and lunar. You also can do time-lapse photography at various speeds. You can select these with an easy-to-see and easy-to-use control called the Mode Dial. This dial also turns the mount off, and with a built-in LED, the selected mode was visible in the dark.

You can use the mount either north or south of the equator with a flip of a switch. The various options also will let you perform horizontal and vertical rotation time-lapse photography.

One other nice-sounding feature is the DSLR Shutter Control Cable, which connects to a 2.5mm three-segment stereo jack built into the mount. When you use it, the cable provides a preprogrammed camera shutter control interface for time-lapse photography. You will require the cable specific to your DSLR camera; ones for Canon, Nikon, Olympus, and Sony cameras are available. I was not able to try this particular component.

You can download firmware upgrades to your computer at no cost. You'll find the latest version at www.skywatcherusa.com. Once you are on the Sky-Watcher USA site, click the "Support Center" link. The mount connects directly to your computer with a mini USB cable.

PRODUCT INFORMATION

Sky-Watcher USA Star Adventurer

Type: Equatorial mount

Tracking rates: Sidereal; 0.5x, 2x, 6x, and 12x sidereal; solar; and lunar

Power: USB or four AA batteries

Payload: 11 pounds (5 kilograms)

Included: Polar scope with illuminator; DSLR interface for automatic shutter control; Astro Package comes with declination bracket; Photo Package comes with ball-head adapter

Price: $339 for Astro Package; $319 for Photo Package

Contact: Sky-Watcher USA
475 Alaska Avenue
Torrance, CA 90503
[t] 310.803.5953
[w] www.skywatcherusa.com

Explore Scientific's ED80 refractor weighs 7.5 pounds (3.2 kilograms), well within the payload limit of the Star Adventurer mount. MIKE REYNOLDS

Testing

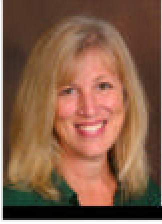
I tested several instruments on the Star Adventurer mount, including a 3.2-inch Explore Scientific refractor, a 3.2-inch Daystar SolaREDi Hα telescope, and a Canon 5D Mark II DSLR with different lenses. The specs provided by Sky-Watcher USA note that the Star Adventurer can carry a maximum payload of 11 pounds (5kg). All three of the instruments I mounted on the Star Adventurer were under that maximum. The SolaREDi was the heaviest at a bit over 8 pounds (3.6kg). And for each instrument, the mount performed admirably.

In the field, alignment was quick, made so with the integrated polar scope and its illuminated reticle. The rest of the setup was also fast. I tested the drive under different uses, from simple imaging through my DSLR to high-magnification observing. For such a light "grab-and-go" mount, I found the tracking to be quite good with few periodic errors.

The bottom line

Sky-Watcher USA's Star Adventurer is a solid, compact, and lightweight tracking mount with a wide array of excellent features and options. For an observer or imager like myself, ease of setup and simple operation really prove helpful. I know the airlines will appreciate the small features — as will my wife.

Star Adventurer accessories include (left to right) the ball-head adapter, counterweight set, and declination bracket. SKY-WATCHER USA



ASTROSKETCHING

BY ERIKA RIX

Think positive

The author captured NGC 7008 with a 16-inch f/4.5 reflector on a non-tracking Dobsonian mount, using an Oxygen-III filter and an 8mm Plössl eyepiece for a magnification of 225x. She sketched both targets using a Gelly Roll 08 white gel pen, a white watercolor pencil, a white Conté crayon, a No. 2 blending stump, and black Strathmore Artagain paper. The diameter of the sketch circle is 3.5 inches, and the sketches have been rotated so that north is at the top, west to the right. ALL SKETCHES BY ERIKA RIX

I have the tendency to be either too light- or heavy-handed with graphite when rendering deep-sky objects on white paper. It's a coin toss as to how the object might look after inverting the scanned drawing to a positive image — the faint details could disappear, or the denser areas could become overly bright.

Switching to black paper eliminates the guesswork. By using white media in lieu of graphite, you can create a positive image directly at the eyepiece. Along with quality black paper and blending stumps, the basic sketch kit includes (in white) colored pencils, a gel pen, and a pastel or charcoal pencil. I'll use a sketch of the Fetus Nebula (NGC 7008) as an example.

Reaching 98" by 75" across at magnitude 10.7, this bluish planetary nebula lies in the constellation Cygnus the Swan, nearly midway between Deneb (Alpha [α] Cygni) and Alderamin (Alpha Cephei). It's nestled just next to the northern component of SAO 33060, a striking gold and blue binary star system with an 18" separation.

The author observed the Fireworks Galaxy (NGC 6946) using a 16-inch f/4.5 reflector on a non-tracking Dobsonian mount with a 12mm eyepiece for a magnification of 150x.

Through a 4-inch instrument, NGC 7008 has a crescent shape and several nearby doubles. Nodules on the north-northeast and the south-southwest rims show through a 10-inch telescope, and 16-inch apertures reveal its magnitude 13.2 central star, along with superimposed stars on the western and eastern limbs at 13th and 14th magnitudes. Nebulosity contrast improves with an ultra-high contrast or Oxygen-III filter.

Following a typical sketch sequence, add the brightest stars first with a gel pen. The colored pencil is better suited for the dimmer stars because its waxy base produces fainter markings. Once the star field is complete, lightly rub the tip of a blending stump through a patch of pastel outside the sketch area, and then use it to draw the nebula.

The second sketch is of the Fireworks Galaxy (NGC 6946). It's located 2° south-southwest of Eta (η) Cephei on the border between the constellations Cepheus and Cygnus. At low power, this face-on spiral fits in the same field of view as open cluster NGC 6939, just 39' northwest. The galaxy's high levels of star formation and destruction invoke the explosive displays for which it's named.

Through a 4-inch scope, the Fireworks — at magnitude 8.8 and measuring 11.5' by 9.8' across — is a soft haze just north of a triangle of 7th- and 8th-magnitude stars. With a 10-inch instrument, its center brightens and the object becomes elongated east to west. A concentrated core and knotted arm structures are visible through a 16-inch telescope.

Drawing with pastel and charcoal produces a matte finish that smudges and erases easily. It also has the ability to accept multiple layers over itself. That translates to significant control with a blending stump while you build up the structural layers of the Fireworks Galaxy.

Questions, comments, or suggestions? Contact me at erikarix1@gmail.com.

NEW PRODUCTS

Attention, manufacturers: To submit a product for this page, email **mbakich@astronomy.com**.

Mount adapter

JMI Telescopes
Lakewood, Colorado

JMI's Train-N-Track Motor Drive for the Explore Scientific Twilight I alt-azimuth mount provides trained tracking for 10 minutes or more. It installs in minutes and runs on eight AA batteries. It comes with a hand unit featuring high-speed slewing and variable speed.

Price: $279
[t] 800.247.0304
[w] www.jmitelescopes.com

Pier

iOptron, Woburn, Massachusetts

iOptron's Tri-Pier combines the strength and stability of a pier with the leveling flexibility of a tripod. It weighs 25.6 pounds (11.6 kilograms) and will carry a 220-pound (100kg) payload. The company constructed the pier and leg tops out of aluminum and the leg extensions out of stainless steel.

Price: $598
[t] 866.399.4587
[w] www.ioptron.com

8-inch refractor

iStar Optical, Marana, Arizona

iStar's Phoenix WXT 204–6 LT is an achromatic refractor with a doublet objective and a focal ratio of f/5.9. The optical tube includes a William Optics DDG, dual-speed, 360° rotatable, 2" rack-and-pinion focuser.

Price: $3,765
[t] 239.898.3551
[w] www.istar-optical.com

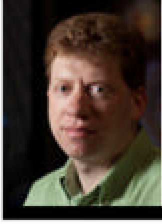
Astroimaging DSLR

Nikon, Melville, New York

Nikon's D810A is a DSLR optimized for imaging nebulae. It contains a 36.3-megapixel CMOS chip (for high-resolution images up to 7360x4912 pixels), has an ISO range from 200 to 12,800, and offers 14 shutter speeds from 4 to 900 seconds, as well as Bulb and Time settings. Nikon optimized its chip for Hydrogen-alpha light.

Price: $3,799.95
[t] 800.645.6687
[w] www.nikonusa.com

SEE REPORTS ON 350+ PRODUCTS AT **www.Astronomy.com/equipment.**



COSMICIMAGING

BY ADAM BLOCK

The storied sky

People often ask how I choose processing techniques. Beyond the rigorous steps of calibration, what remains are artistic choices that blend style and editing. Asking which technique to use next, in a cookbook fashion, is approaching image processing backward. Instead, ask: What do I want the image to communicate that is thought-provoking? In this column, I'll give two examples of pictures that tell fascinating stories and the processing decisions that gave them voice.

Globular clusters NGC 6522 and NGC 6528 (left image) float amid the seemingly uncountable stars toward the center of our galaxy. Here, we look through Baade's Window and see more stars than normal because of a break in the dust clouds that pervade the area. In addition, two globular clusters, each representing a hyperbole of a stellar swarm, scream that stars and their sheer number are part of the story here.

What did Johannes Kepler, Heinrich Olbers, and even Edgar Allan Poe see in their mind's eye when they considered an infinite universe of stars while trying to reckon with the darkness of the night sky? This stellar field could represent something close. And I wanted the picture to communicate the story of Olbers' paradox, which asks why, if the universe is infinite, we don't see stars covering the sky.

When processing the image, I applied a few more iterations to the deconvolution than I might otherwise do for a large diffuse object. I also masked this sharpened image less when blending it with the original. (See my January 2015 column about masks and deconvolution online at www.Astronomy.com/Block.) I then used an unsharp mask on the entire image at a value that was less than the average profile of stars. This acts as an edge enhancement and prevents stars from looking "connected" and indistinct.

I also brightened the image aggressively. Normally, stars cause visual confusion (see June 2015's column about getting the maximum out of the minimum filter), but in this case we want the stars emphasized. Finally, when applying the mask for noise reduction, I was careful that "Smoothing" only act on the darkest pixels so the faintest stars didn't dim.

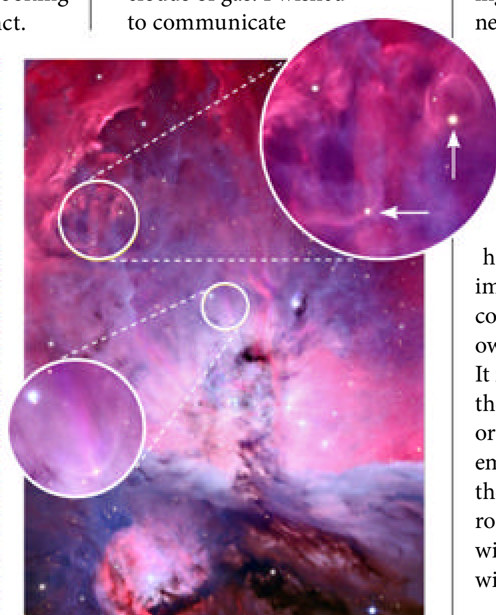
My second example is the Orion Nebula (M42, right image), which, even for all of its fame, holds untold stories. The stellar winds of embedded stars blow bubbles within the clouds of gas. I wished to communicate the motion of the gases in the nebula, so, compared to the above example, I needed to take a gentler approach.

Note that some of the bubbles shown are not centered on the stars. This is because the winds from the central stars are so strong that structures are blown back radially. Indeed, a star near the center has developed a beautiful bow shock due to the onslaught. Any high-contrast processing adjustments, such as high-pass filters and unsharp masks, reduce the translucent edges of the bubbles to stark boundaries that appear as nothing more than texture of the nebula. So, I monitor these structures at each processing step knowing that certain adjustments will greatly impact their appearance.

In these examples, my background in astronomy helped me find inspiration to highlight elements in the images. I encourage you to find compelling attributes to your own astrophotographic subjects. It may be that a single feature in the image is the starting point, or it could be that the subject embodies a more conceptual theme. With this in mind, the road to processing your images will be more direct because you will have a clear destination.

In my next column, I will show how to create field-of-view indicators without specialized commercial software.

NGC 6522 (upper right), NGC 6528 (lower left), and the multitude of stars within this region inspired the author to create a scene illustrating Olbers' paradox. ALL IMAGES: ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA



For this image of the Orion Nebula (M42), the author wanted to show how already formed stars within the cloud create bubbles of thicker material.

BROWSE THE "COSMIC IMAGING" ARCHIVE AND FIND VIDEO TUTORIALS AT **www.Astronomy.com/Block.**

FROM OUR INBOX

Corrections

In the March issue (p. 73), we stated that Saturn's moon Fornjot has the largest orbital period in the solar system. The current record holder is actually Neptune's moon Neso, which has a period of 9,880 days. **— *Astronomy* Editors**

On p. 67 of our March issue, the correct time it would take to drive a car to the nearest star at 70 mph should have been 40.6 million years. **— *Astronomy* Editors**

We welcome your comments at Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; or email to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

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2. Sweepstakes Period. The Sweepstakes begins on March 24, 2015 at 12:00:00 a.m. Central Time, and all entries must be transmitted online no later than July 24, 2015 at 11:59:59 p.m. Central Time.

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6. Prize Restrictions. No cash equivalent or prize substitution permitted. All prizes subject to the guarantees/warranties of the manufacturer. Any applicable federal, state, and/or local taxes are the responsibility of the winner. For prizes of $600 or more in value, winner's Taxpayer I.D. will be required to issue a Form 1099-MISC showing prize ARV as income.

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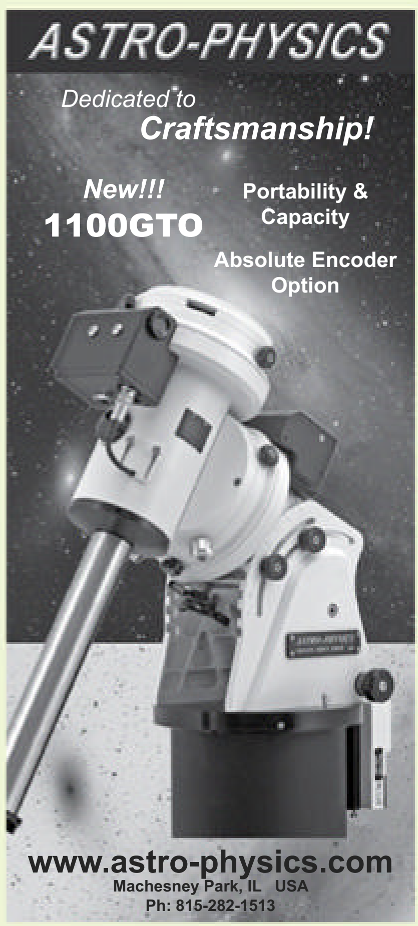

INDEX *of* ADVERTISERS

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READER GALLERY

1. TOTALITY No. 1
This wide-angle shot reveals the Moon's shadow cone as well as Venus to the upper left of the eclipsed Sun. (Canon EOS 6D DSLR, 17mm f/2.8 lens set at f/4, ISO 400, ⅓- and ⅙-second exposures, taken March 20, 2015, from Longyearbyen, Svalbard, Norway) • ***Tunç Tezel***

2. TOTALITY No. 2
In the instants before and after totality, the diamond ring occurs as the last bit of the Sun's brilliant disk creates the diamond and the arc of the corona and prominences form the ring. (Canon 5D Mark II DSLR, 50mm Maksutov lens at f/8, 2x teleconverter, ISO 800, 1/800-second exposure, taken March 20, 2015, from Longyearbyen, Svalbard, Norway) • ***Tunç Tezel***

3. TOTALITY No. 3
The Sun hangs low over the hills that hug Longyearbyen to the south. (Canon 5D Mark II DSLR, 35mm f/2 lens set at f/2.8, ISO 400, ⅓- and ⅙-second exposures, taken March 20, 2015, from Longyearbyen, Svalbard, Norway) • ***Tunç Tezel***

Send your images to:
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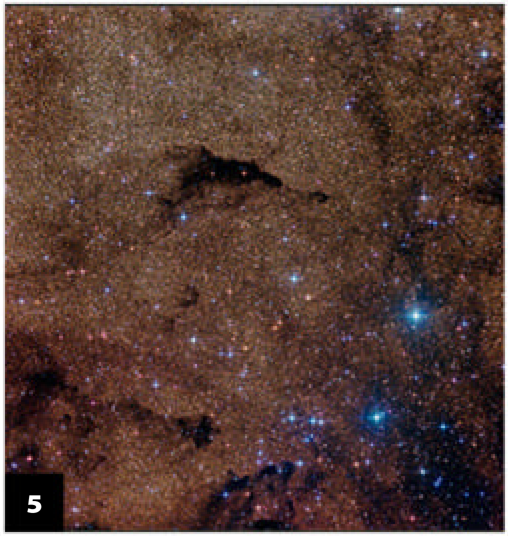

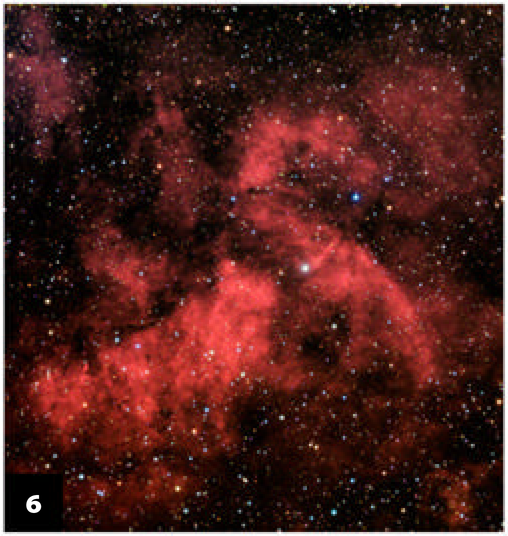

4. PROUD MESSIER OBJECT
M85 (center) is a lenticular galaxy some 60 million light-years away in the constellation Coma Berenices. Two galaxies flank it: NGC 4394 lies to its left, and smaller IC 3292 is to the right. (Telescope Engineering Company TEC-200ED refractor at f/9, SBIG STL-11000M CCD camera, LRGB image with exposures of 255, 180, 180, and 180 minutes, respectively) • ***Lee Buck***

5. DARK MAMMAL
The Dolphin Nebula (Barnard 252) is a cloud of dust and cold gas in the constellation Scorpius the Scorpion. Eventually, such objects become star-forming regions. (16-inch Dream Telescopes Astrograph at f/3.75, Apogee Alta U16M CCD camera, RGB image with 30 minutes of exposure through each filter) • ***Kfir Simon***

6. RED ROVER
Lynds Bright Nebula 315 is an emission nebula in the constellation Cygnus the Swan. Atoms of hydrogen in such objects emit light that they absorbed as ultraviolet energy from nearby stars. The relatively bright star at the center is magnitude 7.1 HD 195592. (3.6-inch Astro-Tech AT90EDT refractor at f/6.7, SBIG ST-8300M CCD camera, HαRGB image with exposures of 360, 40, 40, and 40 minutes, respectively) • ***Dan Crowson***

7. LUNAR GREEN FLASH
The Moon, one day before its Full phase, rises next to Évora Cathedral. To capture the scale of these objects, the photographer positioned himself 1.5 miles (2.4 kilometers) away from the cathedral, which dates from the 12th century. (3.2-inch Astro Professional ED80 refractor at f/7, Canon 50D DSLR, ISO 1600, 1⁄10-second exposure, taken January 5, 2015, from Évora, Portugal) • ***Miguel Claro***

BREAK
THROUGH

Recipe for mayhem

Step 1: Launch two gas-rich spiral galaxies on a collision course. Step 2: Sit back and enjoy the show. This Hubble Space Telescope photo delivers the tasty result as NGC 7714 (seen here) bumps into NGC 7715 (just off the image's top edge). The interaction sparked a firestorm of star formation that shows up in a brilliant galactic nucleus and scads of bluish star clusters. Meanwhile, tidal forces gave birth to two long stellar streamers and an expanding gold ring of Sun-like stars. NGC 7714 lies in the constellation Pisces approximately 100 million light-years from Earth. NASA/ESA

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MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

September 2015: When worlds align

September begins with a superb view of **Mercury**, clearly visible in the western sky shortly after sunset. The innermost planet reaches greatest elongation September 4, when it lies 27° east of the Sun and appears nearly 15° above the horizon an hour after sunset. The world shines at magnitude 0.1 and will be easy to identify below Spica, Virgo's brightest star.

September is the best month this year to view Mercury in the evening sky. Its relatively high altitude means you should have good seeing conditions to watch the planet's changing appearance through a telescope. During the month's first week, Mercury shows a 7"-diameter disk that is slightly more than half-lit. The phase shrinks to 50 percent illumination September 7 and then becomes a pleasing crescent as the planet draws closer to the Sun. Mercury also grows larger as September progresses, reaching 9" across by midmonth. The planet soon disappears in the twilight as it heads toward inferior conjunction on the 30th.

If you scan higher in the western sky, past Spica and nearly to Scorpius, you'll find **Saturn** near the eastern edge of the dim constellation Libra the Scales. Shining at magnitude 0.6 in mid-September, the ringed planet is the brightest object in this region.

Saturn's high altitude in early evening makes it a spectacular subject for those with telescopes. The giant world's disk measures 16" across at midmonth while the glorious rings span 37" and tilt 24° to our line of sight. It's a great object if you want to introduce newcomers to the glories of the night sky.

The ringed planet sets before midnight local time this month. You then have to wait several hours before another naked-eye planet comes into view.

The first to appear is **Venus**, which rises shortly before 5 A.M. local time in early September and around 3:30 A.M. late in the month. Although this inner planet always appears bright, it is exceptionally so this month. It peaks at magnitude –4.8 on September 21 and remains within 0.3 magnitude of that mark all month.

Venus' telescopic appearance changes rapidly during September as it pulls away from the Sun. On the 1st, the planet appears 52" across and just 9 percent lit. By the 30th, Venus' apparent diameter has dwindled to 34" and the Sun illuminates one-third of the disk.

By late September, two more planets climb into view. **Mars** rises first, some 10° to the lower right of Venus. Don't confuse it with Regulus, Leo's brightest star, which lies 3° above the Red Planet. Mars shines at magnitude 1.8, some 50 percent dimmer than the star.

About 20 minutes after Mars rises and just an hour before the Sun does, **Jupiter** pokes above the eastern horizon. The giant world shines far brighter (magnitude –1.7) than its planetary neighbor and will be easier to spot in the predawn twilight. Binoculars will help you spy all these objects against the brightening sky. Unfortunately, the low altitudes of Mars and Jupiter render them disappointing through a telescope.

The Moon and Sun provide two additional highlights this month. On September 13, viewers with clear skies in southern Africa, southern Madagascar, and parts of the Indian Ocean and Antarctica will witness a **partial solar eclipse**. From Cape Town, South Africa, the eclipse is underway at sunrise and reaches maximum at 5h43m UT. The Moon then obscures 30 percent of the Sun.

A **total lunar eclipse** graces the skies above Africa, South America, the Atlantic Ocean, and the eastern Pacific Ocean on September 28. The partial phase begins at 1h07m UT and runs until 4h27m UT. Totality lasts for 72 minutes, from 2h11m to 3h23m UT.

The starry sky

The International Astronomical Union defined borders for the sky's 88 constellations in 1930. They are named after real and imaginary creatures, objects, and shapes. Only some of these constellations have patterns that resemble the things for which they are named, however. Crux the Cross is a superb example, as are Scorpius the Scorpion and Orion the Hunter.

Scattered across the sky are many distinctive groups of stars that are not official constellations. Some of these so-called asterisms form just part of a large constellation while others stretch across constellation boundaries. A number of these striking patterns adorn the September evening sky.

Sagittarius the Archer stands high in the northeast as darkness falls. But try observing this constellation in an unusual way: Lie on your back with your head arched slightly backward so you see Sagittarius with north at top. This trick will help you see the Teapot asterism, a well-known pattern for observers in the Northern Hemisphere, where the shape appears upright. Sigma (σ) and Tau (τ) Sagittarii form the Teapot's handle while Zeta (ζ), Phi (ϕ), Delta (δ), and Epsilon (ε) are the main body, Gamma (γ) is the spout, and Lambda (λ) is the lid.

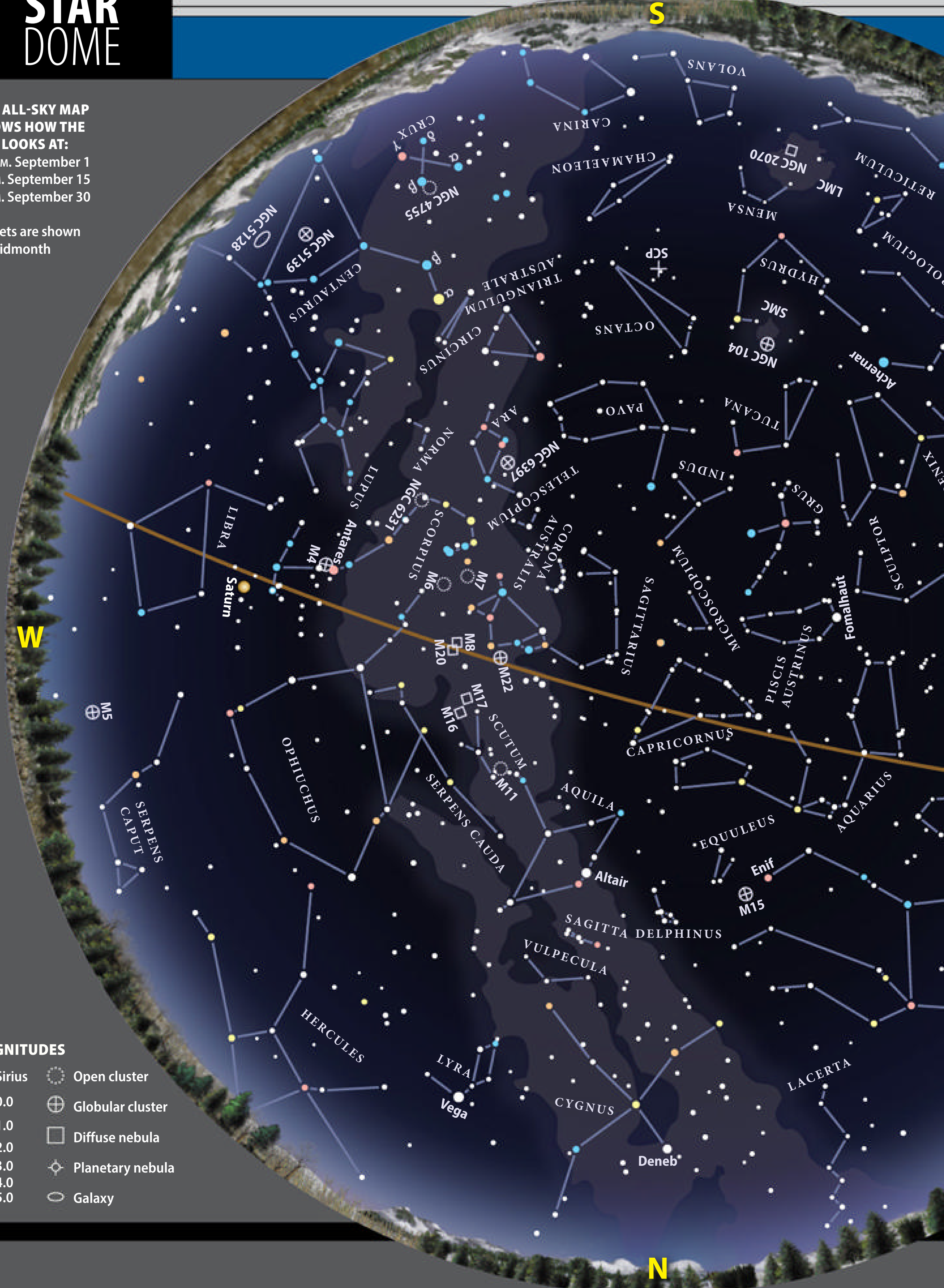
The second asterism I'd like you to view this month is a binocular object in the constellation Vulpecula the Fox. The Coathanger asterism lies at a declination of 20° and climbs highest in the northern sky early on September evenings. You can find this object some 13° north-northwest (to the lower left) of magnitude 0.8 Altair in Aquila the Eagle.

Cataloged as Collinder 399 and often called Brocchi's Cluster (after the 20th-century American amateur astronomer D. F. Brocchi), this asterism is not a true cluster but merely a chance alignment of stars. The grouping looks remarkably like a coathanger that spans nearly 2°. The pattern's brightest member is 5th-magnitude 4 Vulpeculae while the faintest glows at 7th magnitude. Oddly enough, even though the Coathanger lies in the northern part of the celestial sphere, it appears upright only to those of us in the Southern Hemisphere.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
10 P.M. September 1
9 P.M. September 15
8 P.M. September 30

Planets are shown at midmonth



MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

HOW TO USE THIS MAP: This map portrays the sky as seen near 30° south latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

STAR COLORS: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white without optical aid.

Illustrations by *Astronomy*: Roen Kelly

SEPTEMBER 2015

Calendar of events

1 Neptune is at opposition, 4h UT

The Moon passes 1.1° south of Uranus, 16h UT

4 Mercury is at greatest eastern elongation (27°), 10h UT

5 The Moon passes 0.5° north of Aldebaran, 6h UT

Venus is stationary, 9h UT

Last Quarter Moon occurs at 9h54m UT

6 Asteroid Metis is at opposition, 3h UT

10 The Moon passes 3° north of Venus, 6h UT

The Moon passes 5° south of Mars, 23h UT

13 New Moon occurs at 6h41m UT; partial solar eclipse

14 The Moon is at apogee (406,464 kilometers from Earth), 11h27m UT

15 The Moon passes 5° north of Mercury, 6h UT

Asteroid Ceres is stationary, 18h UT

17 Mercury is stationary, 13h UT

19 The Moon passes 3° north of Saturn, 3h UT

21 First Quarter Moon occurs at 8h59m UT

Venus is at greatest brilliancy (magnitude –4.8), 15h UT

23 September equinox occurs at 8h21m UT

24 Mars passes 0.8° north of Regulus, 17h UT

Pluto is stationary, 19h UT

26 The Moon passes 3° north of Neptune, 10h UT

27 Asteroid Juno is in conjunction with the Sun, 4h UT

28 The Moon is at perigee (356,877 kilometers from Earth), 1h46m UT

Full Moon occurs at 2h50m UT; total lunar eclipse

29 The Moon passes 1.0° south of Uranus, 1h UT

Asteroid Vesta is at opposition, 3h UT

30 Mercury is in inferior conjunction, 15h UT

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**